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# XXXIV.—The Variation of Young's Modulus under an Electric Current. By Henry Walker, M.A., B.Sc. *Communicated by* Professor J. G. MacGregor, F.R.S.

(MS. received May 20, 1907. Read June 24, 1907.)

## Object of the Investigation.

This investigation was carried out for the purpose of extending to other substances an inquiry into the effect of an electric current on Young's Modulus, which was carried out by Miss Noyes on a steel wire at Cornell University, and described in the *Physical Review*, No. 4, vol. ii. In the investigation of Miss Noyes, the wire under examination was heated by a coil, the current being supplied by a storage battery. To vary the method of heating, the current was also sent through the wire with the expectation that the same effects would be obtained as when the wire was heated by the coil. This, however, was found not to be the case, and Professor Nichols, under whose superintendence the investigation was carried out, in his *Laboratory Manual of Physics*, vol. ii. p. 293, states that an extension of the inquiry to other materials than iron would be of interest.

In the present series of experiments the behaviour of steel, soft iron, copper, and platinum was examined when a current was passed through the wires.

## General Plan of the Experiments.

The wire to be tested was mounted horizontally on a solid block of wood and carefully adjusted so as to be parallel to lines ruled on it. Care was also taken to see that the wire was horizontal. It was placed in a glass tube of about 4 cms. diameter for protection against air-currents. This tube was 130 cms. long, and two holes were drilled in it, whose centres were 98 cms. apart, through which the positions of two marks on the wire were observed by microscopes. To prevent currents of air, the ends of the tube were stopped with cotton-wool. The temperature of the wire was determined by its electrical resistance.

The microscopes employed had micrometers in the eye-pieces which were intended to be ·01 mm. between each division; but on carefully measuring them it was found that in the right-hand microscope each division was ·00950 mm., and in the left-hand, ·00944 mm. It was possible to estimate a tenth of a division.

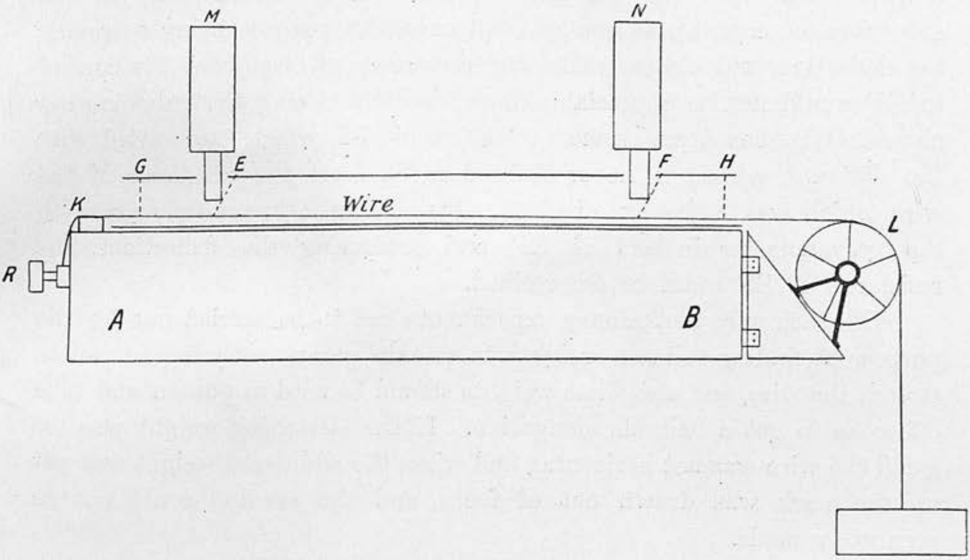
The temperature coefficient of the electrical resistance of the wires was determined by coiling them on a glass tube covered with silk, and immersing them in a vessel of oil. The resistance was determined for temperatures ranging from near zero to 150°. Great care was taken to obtain accuracy in measuring the various temperatures at which the resistance was determined. The temperature was taken by a platinum resistance thermometer. It had been calibrated by finding its resistance at 0° and 100°, and drawing the graph on the assumption that its resistance was zero at $-240°$, according to the results obtained by Professor Callendar. This graph was then tested by finding the resistance in the vapour of boiling ethyl-alcohol and of boiling amyl-alcohol, and the differences were within the limits of experimental error.

The method adopted for finding the temperature coefficient of resistance was the following:—The platinum thermometer was immersed in the oil close to the wire whose resistance was being determined. Two ordinary mercury thermometers were also placed in the vessel, one near the top, the other near the bottom, their use being to ensure that the temperature did not vary while the resistances of the wire and of the platinum thermometer were being determined. The oil was kept well stirred; when it reached a temperature at which a reading was desired the flame was carefully regulated; and when the mercury thermometers had remained steady for not less than five minutes, the resistances of the thermometer and the wire were taken in the usual way by a metre-bridge. The resistance of the copper side-pieces of the bridge had been determined, the wire calibrated, and, to provide against any alteration in these through their temperature being raised by heat from the oil bath, the connecting wires were several metres long. The resistance of the connecting wires was allowed for by measuring that of similar wires lying parallel to them.

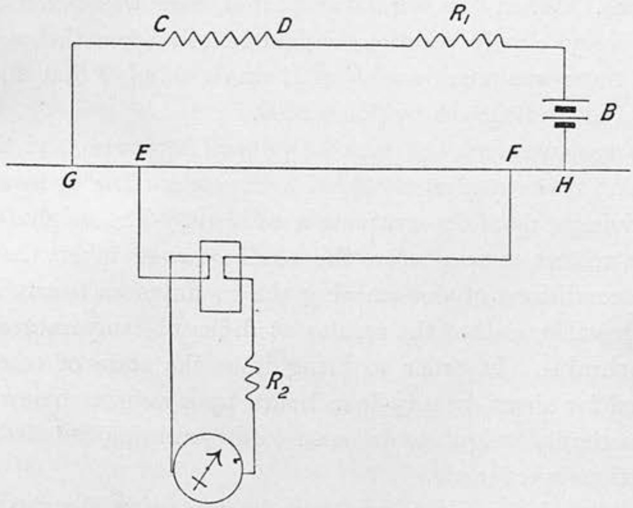
The diameter of each wire was determined by weighing a measured length in air and in water, and calculating the diameter from the density. The diameter at different points was also measured by the micrometer gauge, and the average of the two methods was that used in the calculations.

## Arrangement of the Apparatus.

AB is the wooden block, GH the glass tube resting on wooden blocks, and having openings at E and F, through which the readings were taken by the microscopes M and N. The wire was fastened at R, passed over a grooved piece of wood at K, through the tube and over the wheel L to a pan in which the weights were placed. The wheel was mounted on anti-




friction rollers. A pasteboard tube protected the portion of the wire between the glass tube and the wheel from currents of air. The wires




for the current and for measuring the resistance were attached near G and H.

The plan of connections for measuring the resistance is given in fig. 2, the fall of potential method being used. The portion EF of the wire to be tested was in circuit with the battery B, the rheostat $R_1$ being adjusted so as to give the desired temperature. EF was connected in multiple arc with the galvanometer G. The resistance $R_2$ in the galvanometer circuit was one of 5000 ohms, its purpose being to reduce the deflection, and also to make the resistance so large that the current in EF would not be appreciably diminished by closing the galvanometer circuit. CD was a resistance in the circuit EF which was varied with the different wires; it never differed much from the resistance of the wire which was under examination. By placing it in multiple arc with the galvanometer instead of EF, and comparing the deflections, the resistance of EF could be determined.

With each wire preliminary experiments had to be carried out for the purpose of finding suitable weights to remain permanently in the pan to stretch the wire, and also what weights should be used to put on and take off so as to get a suitable elongation. If the stretching weight was too small the wire was not horizontal, and when the additional weight was put on the mark was drawn out of focus, and the reading could not be accurately made.

For most of the determinations four sets of readings were taken, each set consisting of the changes in length produced by adding the elongation weight and then removing it, thus making the result the average of eight determinations. When the wire was heated, care was taken to see that it returned very closely to the original length when the weights were removed; if there was much variation, it was concluded that the temperature had altered, and the set was discarded.

For each measurement, the microscope was set twice, and the average reading taken; if the readings differed from one another by more than one-tenth of a division, more observations were made. The weights were placed in position a minute or two before the readings were taken, the aim being to make the conditions of determining the modulus as nearly identical in all cases as possible, so that the results at different temperatures might be strictly comparable. In order to bring it to the state of ease, each wire was stretched for about twenty-four hours by a weight somewhat greater than the maximum weight to be used in determining the modulus, before any observations were made.

The procedure in each case was first to determine the modulus at the temperature of the room before any current had been passed, then to pass a weak current by which the temperature was raised through two or three degrees and again to determine the modulus. After this, the current was gradually increased and readings taken at various temperatures. When it was found that the modulus was approaching a turning value, the readings were taken at shorter intervals, so that the behaviour could be accurately represented in its neighbourhood.

When the highest temperature to which it was thought necessary to carry the experiment had been reached, the current was gradually diminished and readings taken with a decreasing current. In all the graphs the readings with the increasing current are denoted by circles, and those with the decreasing current by crosses.

The formula used in computing the modulus was—

$$M = \frac{P.L}{a.l},$$

where

P = stress in dynes.
L = length of wire.
$a$ = area of cross-section.
$l$ = elongation.

The results are given in the C.G.S. system of units, the value of $g$ at Stranraer being 981·4.

In order to see if the friction of the pulley introduced an error, pieces of each wire from the same coil were suspended vertically. To make the conditions of this set of experiments as nearly similar as possible as when the wires were horizontal, the tube was clamped in a vertical position with the wire inside it. The ends of the tube were stopped with cotton-wool, and the ends of the wire outside the tube were protected from air-currents by pasteboard cylinders. The same weights were used as when the wire was horizontal, and the elongations were measured by the microscopes. It was fitted up in a corner of the room and protected from air-currents. The temperature was also taken by the platinum thermometer, three mercury thermometers being placed at different parts of the tube to make sure that the temperature throughout it had become uniform.

### Iron Wire.

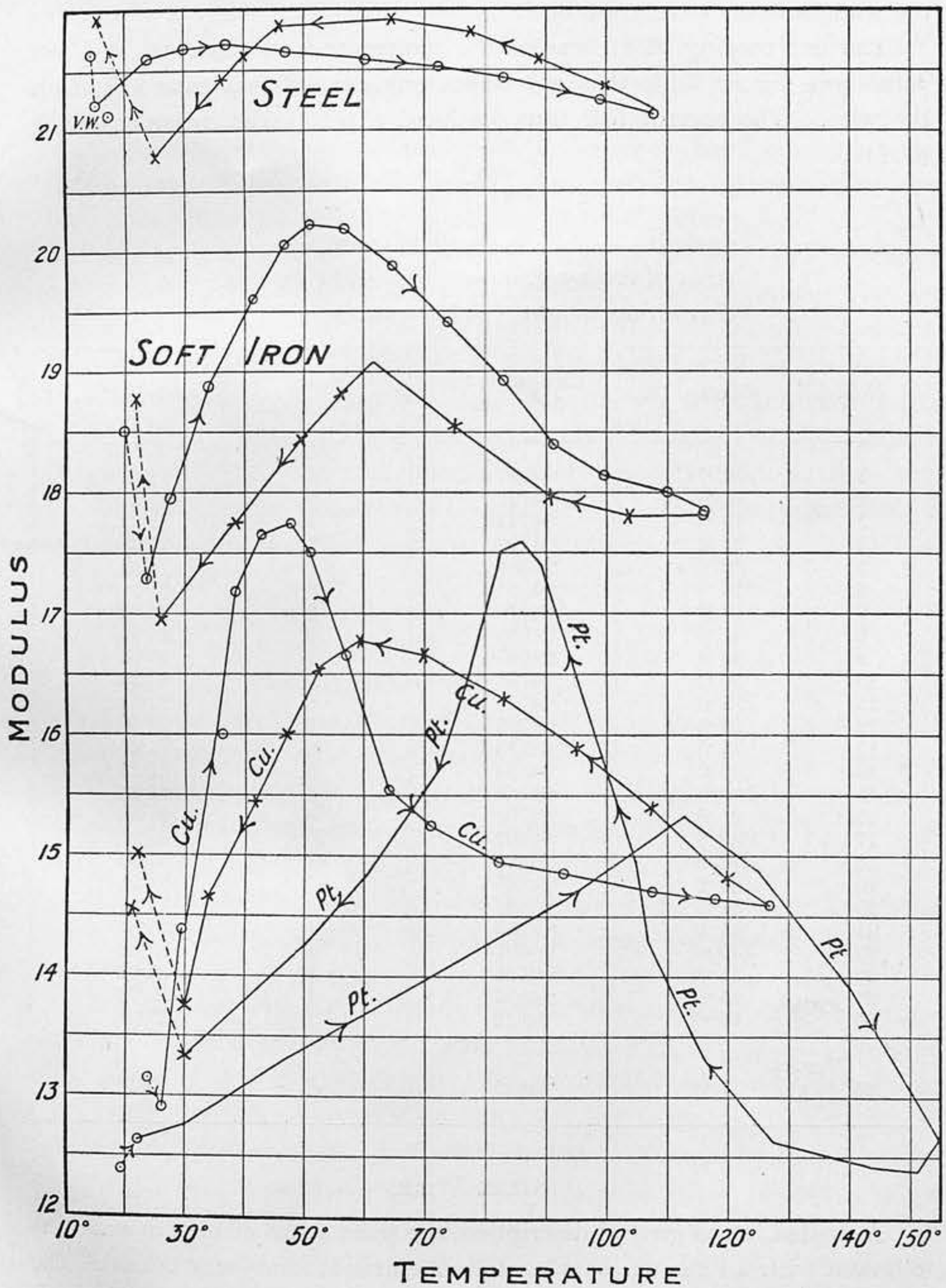
The modulus was first determined without any current, the wire being at the temperature of the room. It was then heated by a weak current by which the temperature was raised about 3°·5, and it was found that the modulus had fallen in value. The strength of the current was next gradually increased, the effect of this increase being to cause a steady rise in the modulus until the temperature had risen to about 53°. Beyond this there was a regular fall in the value, the rate of decrease being less than the rate of increase when the modulus was rising in value. This diminution continued up to the highest temperature to which the experiment was carried, but the rate was not uniform, for at about 105° the rate of decrease fell. Moreover, the modulus did not fall to so low a value as it had when the current was first started. This part of the curve is denoted by the circles.

*Iron Wire.*

Length = 97·9 cms.
Area of cross-section = ·0005474 sq. cms.
Stretching weight = 500 grams.

| No. | Temp. | Elongation for 500 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 1 | 20°·4 C. | ·04741 cm. | 8 | $18{\cdot}51 \times 10^{11}$ |
| 2 | 23 ·9 | ·05073 | 8 | 17·30 |
| 3 | 27 ·5 | ·04880 | 8 | 17·98 |
| 4 | 34 ·2 | ·04658 | 8 | 18·84 |
| 5 | 40 ·8 | ·04482 | 10 | 19·58 |
| 6 | 47 ·1 | ·04387 | 8 | 20·04 |
| 7 | 50 ·6 | ·04347 | 8 | 20·19 |
| 8 | 57 ·0 | ·04357 | 6 | 20·14 |
| 9 | 64 ·9 | ·04421 | 7 | 19·85 |
| 10 | 73 ·9 | ·04526 | 8 | 19·39 |
| 11 | 82 ·8 | ·04633 | 8 | 18·94 |
| 12 | 90 ·7 | ·04764 | 8 | 18·42 |
| 13 | 100 ·2 | ·04833 | 8 | 18·16 |
| 14 | 108 ·0 | ·04880 | 10 | 17·98 |
| 15 | 116 ·1 | ·04916 | 6 | 17·85 |
| 16 | 104 ·3 | ·04935 | 8 | 17·78 |
| 17 | 90 ·5 | ·04880 | 8 | 17·98 |
| 18 | 75 ·0 | ·04736 | 8 | 18·53 |
| 19 | 67 ·2 | ·04623 | 9 | 18·98 |
| 20 | 61 ·8 | ·04588 | 8 | 19·13 |
| 21 | 60 ·6 | ·04626 | 5 | 18·97 |
| 22 | 55 ·6 | ·04663 | 7 | 18·82 |
| 23 | 49 ·5 | ·04771 | 8 | 18·38 |
| 24 | 38 ·7 | ·04958 | 8 | 17·70 |
| 25 | 25 ·3 | ·05174 | 8 | 16·96 |
| 26 | 21 ·3 | ·04686 | 8 | 18·73 |
| Vertical Wire. | | | | |
| 27 | 16 ·1 | ·04852 | 8 | 18·09 |

The current was then gradually diminished in strength, and readings taken at various temperatures. It was found that the value was not so high as when the current was increasing, and about 104° it reached a minimum. From this point on to 62° the rate of increase was nearly the same as the rate of decrease with the increasing current. The reading at 60°·6 is probably incorrect, as it does not lie on any smooth curve that



STEEL
V.W.
SOFT IRON
Cu.
Pt.
MODULUS
12
13
14
15
16
17
18
19
20
21
10°
30°
50°
70°
100°
120°
140°
150°
TEMPERATURE

would pass through the values on opposite sides of it. After this, there was again a steady fall, and at 25°·3, the last reading taken with a current, the value was the lowest obtained.

The last reading of all was at the temperature of the room, and the value was higher than that got before any current was passed through the wire. The current had thus produced a permanent increase in the modulus.

*Steel Wire.*

Length = 97·60 cms.
Area of cross-section = ·0004714 sq. cms.
Stretching weight = 500 grams.

| No. | Temp. | Elongation for 500 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 1 | 13°·7 C. | ·04697 cm. | 8 | $21·63 \times 10^{11}$ |
| 2 | 15 ·0 | ·04791 | 8 | 21·21 |
| 3 | 19 ·0 | ·04744 | 4 | 21·42 |
| 4 | 24 ·2 | ·04702 | 6 | 21·58 |
| 5 | 30 ·0 | ·04686 | 6 | 21·68 |
| 6 | 34 ·0 | ·04682 | 8 | 21·70 |
| 7 | 37 ·0 | ·04678 | 8 | 21·72 |
| 8 | 41 ·0 | ·04682 | 10 | 21·70 |
| 9 | 46 ·4 | ·04697 | 7 | 21·63 |
| 10 | 59 ·2 | ·04706 | 8 | 21·59 |
| 11 | 72 ·6 | ·04717 | 8 | 21·54 |
| 12 | 83 ·2 | ·04735 | 8 | 21·46 |
| 13 | 98 ·6 | ·04779 | 8 | 21·26 |
| 14 | 108 ·0 | ·04814 | 9 | 21·15 |
| 15 | 100 ·3 | ·04763 | 6 | 21·33 |
| 16 | 88 ·8 | ·04702 | 8 | 21·58 |
| 17 | 85 ·8 | ·04697 | 10 | 21·63 |
| 18 | 76 ·9 | ·04662 | 12 | 21·79 |
| 19 | 64 ·2 | ·04637 | 9 | 21·91 |
| 20 | 57 ·0 | ·04631 | 8 | 21·94 |
| 21 | 45 ·0 | ·04659 | 8 | 21·82 |
| 22 | 40 ·3 | ·04691 | 8 | 21·66 |
| 23 | 34 ·5 | ·04750 | 8 | 21·39 |
| 24 | 25 ·0 | ·04891 | 8 | 20·77 |
| 25 | 15 ·6 | ·04622 | 8 | 21·98 |
| Vertical Wire. | | | | |
| 26 | 17 ·3 | ·04815 | 6 | 21·10 |

STEEL WIRE.

As stated in the general description, the same series of experiments was followed with all the wires; therefore the first reading was taken at the temperature of the room before any current had been passed. A weak current was then used, and it produced a fall in the modulus. The current was next increased, with the result that the value rose until a maximum was reached about 34°, after which there was a regular decrease until the temperature was 108°, this being the highest temperature reached. Throughout the latter part of this curve the rate of decrease in the modulus was less than that of increase when the value was rising.

The current was then diminished, with the result that the modulus rose until the temperature had fallen to 57°, the maximum at this point being higher than that got with the increasing current. Throughout this stage the rate of increase was higher than the rate of fall with the increasing current. Below this temperature the modulus diminished along with the temperature, the rate of fall being greater than that at the same temperature with the increasing current, so that the graph cuts at about 41°·5. The fall was then quite regular to 25°, this having been the last reading taken with a current. The value was finally determined at the temperature of the room without a current, and found to be higher than what it was before any current had been passed. There was therefore a permanent increase in the value of the modulus.

## Copper Wire.

The modulus was determined at the temperature of the room, and when a weak current was passed it produced a fall in its value. As the current was increased, there was a rapid increase in the modulus, which continued until the temperature had risen to about 45°, when a maximum was reached. Above this temperature there was a diminution which was fairly rapid at first, but the rate was not so great as that of the increase before the maximum. The rate of fall began to alter about 60°, and after 80° it was fairly uniform up to 127°, beyond which point the readings were not continued.

The current was then diminished, with the result that the modulus increased in value till the temperature had fallen to about 60°, and throughout this stage the value was higher than at the same temperatures with the increasing current. Until the temperature had fallen to 80°, the rate of increase in the modulus was greater than that of decrease for the increasing current; but at lower temperatures the rate of increase became less than that of decrease, and the two curves cut at about 57°. Further, the maximum with the diminishing current was not so high as that obtained when the current was increasing. The modulus still kept on falling, the rate also being less than that with the increasing current, until the

*Copper Wire.*

Length = 97·50 cms.
Area of cross-section = ·0006026 sq. cms.
Stretching weight = 300 grams.

| No. | Temp. | Elongation for 300 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 1 | 23°·8 C. | ·03630 cm. | 8 | $13·15 \times 10^{11}$ |
| 2 | 25 ·3 | ·03693 | 8 | 12·90 |
| 3 | 29 ·7 | ·03308 | 10 | 14·40 |
| 4 | 35 ·5 | ·02977 | 10 | 16·00 |
| 5 | 39 ·1 | ·02765 | 9 | 17·23 |
| 6 | 42 ·6 | ·02703 | 8 | 17·62 |
| 7 | 47 ·4 | ·02693 | 7 | 17·69 |
| 8 | 50 ·1 | ·02727 | 12 | 17·47 |
| 9 | 56 ·8 | ·02861 | 8 | 16·66 |
| 10 | 59 ·0 | ·02938 | 8 | 16·14 |
| 11 | 63 ·7 | ·03065 | 8 | 15·54 |
| 12 | 70 ·5 | ·03126 | 6 | 15·24 |
| 13 | 81 ·3 | ·03186 | 8 | 14·95 |
| 14 | 93 ·2 | ·03205 | 8 | 14·86 |
| 15 | 108 ·0 | ·03236 | 10 | 14·72 |
| 16 | 118 ·5 | ·03249 | 10 | 14·66 |
| 17 | 127 ·0 | ·03267 | 11 | 14·58 |
| 18 | 119 ·9 | ·03201 | 9 | 14·88 |
| 19 | 107 ·0 | ·03085 | 8 | 15·44 |
| 20 | 95 ·5 | ·02999 | 8 | 15·88 |
| 21 | 82 ·8 | ·02919 | 8 | 16·32 |
| 22 | 70 ·0 | ·02852 | 5 | 16·70 |
| 23 | 60 ·0 | ·02835 | 7 | 16·80 |
| 24 | 52 ·9 | ·02878 | 8 | 16·55 |
| 25 | 47 ·3 | ·02979 | 6 | 16·02 |
| 26 | 41 ·2 | ·03087 | 8 | 15·43 |
| 27 | 34 ·5 | ·03254 | 8 | 14·64 |
| 28 | 30 ·0 | ·03452 | 8 | 13·80 |
| 29 | 21 ·2 | ·03175 | 8 | 15·02 |
| Vertical Wire. | | | | |
| 30 | 16 ·3 | ·03736 | 6 | 12·75 |

temperature reached 30°. On allowing the wire to cool to the temperature of the room, there was a distinct increase in the modulus, so that a permanent change had been produced.

## Platinum Wire.

The behaviour of platinum was different from that of the other three metals. With them the effect of a weak current was to produce a fall in the modulus, whereas in the case of platinum there was a rise with a current which produced a change of less than 3°. As the current was gradually strengthened, there was a steady increase in the modulus; in this case, the rate of increase was slower than with the others, and the maximum not reached until the temperature had risen to 110°. Beyond this the modulus fell till the temperature rose to 155°, the rate of fall being greater than that of rise.

*Platinum Wire.*

Length = 62·10 cms.
Area of cross-section = ·0007548 sq. cms.
Stretching weight = 200 grams.

| No. | Temp. | Elongation for 200 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 1 | 20°·0 C. | ·01302 cm. | 8 | $12·40 \times 10^{11}$ |
| 2 | 22 ·9 | ·01280 | 8 | 12·62 |
| 3 | 29 ·7 | ·01266 | 10 | 12·75 |
| 4 | 46 ·9 | ·01215 | 9 | 13·30 |
| 5 | 61 ·5 | ·01189 | 10 | 13·58 |
| 6 | 66 ·5 | ·01157 | 8 | 13·95 |
| 7 | 81 ·6 | ·01136 | 12 | 14·21 |
| 8 | 93 ·1 | ·01101 | 8 | 14·67 |
| 9 | 101 ·8 | ·01066 | 8 | 15·15 |
| 10 | 107 ·6 | ·01049 | 8 | 15·40 |
| 11 | 113 ·3 | ·01055 | 10 | 15·31 |
| 12 | 124 ·9 | ·01087 | 6 | 14·85 |
| 13 | 139 ·7 | ·01159 | 8 | 13·93 |
| 14 | 155 ·0 | ·01276 | 8 | 12·65 |
| 15 | 150 ·3 | ·01298 | 9 | 12·44 |
| 16 | 143 ·2 | ·01295 | 10 | 12·47 |
| 17 | 128 ·0 | ·01273 | 11 | 12·68 |
| 18 | 116 ·1 | ·01213 | 10 | 13·31 |
| 19 | 110 ·4 | ·01149 | 12 | 14·06 |
| 20 | 107 ·0 | ·01131 | 8 | 14·28 |
| 21 | 104 ·5 | ·01078 | 8 | 14·97 |
| 22 | 100 ·6 | ·01037 | 8 | 15·57 |
| 23 | 96 ·5 | ·009539 | 6 | 16·45 |
| 24 | 89 ·4 | ·009308 | 7 | 17·35 |
| 25 | 85 ·3 | ·009144 | 8 | 17·60 |
| 26 | 82 ·5 | ·009228 | 8 | 17·50 |
| 27 | 77 ·0 | ·009800 | 8 | 16·48 |
| 28 | 71 ·8 | ·01030 | 7 | 15·68 |
| 29 | 60 ·7 | ·01087 | 8 | 14·85 |
| 30 | 50 ·5 | ·01132 | 10 | 14·27 |
| 31 | 40 ·1 | ·01167 | 8 | 13·83 |
| 32 | 29 ·4 | ·01193 | 12 | 13·54 |
| 33 | 20 ·6 | ·01111 | 8 | 14·53 |
| Vertical Wire. | | | | |
| 34 | 20 ·2 | ·01314 | 7 | 12·29 |

The current was then diminished, and this caused a further decrease in the modulus, the minimum being about 148°. Below this, there was a rapid rise in the modulus, and the two curves cut one another at 103°. It continued to increase, the maximum being reached near 86°; it again fell rapidly till about 77°, when the rate of decrease diminished, but the modulus was always higher than at the same temperature with the increasing current. On allowing the wire to cool to the temperature of the room, there was again, as with the other metals, a permanent increase in the value of the modulus.

## A Comparison of the Results.

On reviewing the effects on the metals, we find there are likenesses and differences. With weak currents the initial effect on iron, steel, and copper is a decrease in the modulus; while, on the other hand, there is an increase in the platinum with even the weakest current that was used.

In all cases, an increase in the strength of the current produced a rise in the modulus until a maximum value was attained, the maximum being at different temperatures for the different metals. A further increase in the current then produced a fall in the modulus, which, in each case, was continued up to the highest temperature to which the experiment was carried.

With a diminishing current the effects were more varied. In two cases—viz. the iron and the platinum—there was at first a decrease in the modulus, but a marked difference between them soon made itself manifest. The modulus of the iron was always less than that at the same temperature with the increasing current, while, on the contrary, the modulus of the platinum rose rapidly, and attained a higher value than it had at any temperature with an increasing current.

On the other hand, when a diminished current was passed through steel and copper, the modulus rose in value, and with both a maximum was reached which, in the steel, was higher than the maximum with the increasing current, whereas, in the copper, it was less than the maximum with the increasing current.

In the iron and the steel, the final values with the current were less than the initial values, although the temperatures of these final readings were higher than the initial temperatures with a current; so that the effect of a weak diminishing current is, while it is still passing, to produce a diminution in the modulus. The result, so far as the experiment was carried, was the same with the copper; the value was less than at the same temperature with the increasing current, but, at the lowest temperature at which a reading was taken with the diminishing current, the modulus was higher than the first reading with a current. The platinum, however, differed from the others, inasmuch as the final readings with the diminishing current gave a higher value for the modulus than it had with the initial increasing current.

It is interesting to examine in more detail the results for soft iron and steel. Here we see the effects on the same chemical substance, and therefore, on the assumption that a change in the modulus is caused by a regrouping of the molecules, are able to follow the changes in the groups of molecules, to see when they break up, and how the regrouping has affected the modulus. When the rate of change is small, we may assume that the groups are more stable than when the rate is great.

There is a general similarity in the behaviour of soft iron and steel, but there are also marked differences. With an increasing current the results are, qualitatively speaking, the same. The effect of a weak current is to produce a fall in the modulus; next, as the current increases the modulus also increases, and rises to a higher value than it had before any current was passed; then a maximum is reached, after which a steady decline sets in. There is a great difference, however, in the quantitative results; for, while the increase from the lowest value to the maximum is 14·3 per cent. in soft iron, it is only 2·3 per cent. in steel.

With a diminishing current, there is a marked difference between them. The value of the modulus is smaller in the soft iron than at the same temperatures with the increasing current; whereas, in the steel, it has at first a higher value than it had at the same temperatures with an increasing current. They are, however, alike in this respect, that the modulus in both attains a maximum and then diminishes, the final value being less than with the increasing current at the same temperatures.

After cooling to the temperature of the room, the modulus in each case undergoes a distinct increase. In the soft iron this value is not so great as the greatest value reached with the current, but in the steel it is the highest of all the readings.

It is to be observed that the variation of the modulus in steel is not so great as in iron, and from this we may infer that the groups of molecules are more stable than they are in iron. This result might be expected, for the molecules of steel will be affected to a smaller extent by the circular magnetic field produced by the current than those of soft iron. This expectation, however, is not borne out at all points, for, when one would have looked for the coercive force of the steel to manifest itself, we find a distinct change in the modulus after the current has been stopped.

In all cases, after the wire had been allowed to cool to the temperature of the room, and the modulus determined without any current, it was found there was an increase in its value compared with what it was before any current had been passed through the wire. The final effect, then, in each case was to produce a permanent increase in its value.

It was also intended that brass wire should be put through the same course of experiments, but the temperature coefficient of resistance was so small that it was found impossible to determine the temperature with a suitable degree of accuracy. Probably it would be advisable to determine the temperature of brass and other alloys from the expansion of the wire.

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## XL.—The Variation of Young's Modulus under an Electric Current. By Henry Walker, M.A., B.Sc. *Communicated by* Professor J. G. MacGregor, F.R.S.

### Part II.

(MS. received July 13, 1908. Read same date.)

In my first paper on this subject * the behaviour of soft iron, steel, copper, and platinum was examined. In this paper the experiments have been carried a stage further, viz. the reaching of the cyclically steady state with a small load, the effect when the load is increased, and the heating by the ordinary method.

As the behaviour of the wire when heated by the current was somewhat complicated, I considered it necessary, for purposes of comparison, to heat the wire in some other manner. To effect this, a double-walled tube of tinned iron was made, through the inner tube of which the wire was passed, and the ends plugged with cotton-wool. The wire was horizontal, and measurements were made with the microscopes as in the other experiments. As the turning values of the modulus were all found at comparatively low temperatures, it was not sufficient to determine the modulus at the temperature of the air and at 100° C., and then assume that the decrease was uniform between these two temperatures. To get suitable intermediate temperatures, steam, and the vapours of boiling sulphuric ether, ethyl-alcohol, and amyl-alcohol were passed through the annular space between the two tubes. In this way temperatures of about 35° C., 78° C., 100° C., and 130° C. were obtained. Marks were made on the wires as near to the ends of the tube as it was possible to place them, so as to be in the field of the microscope. Except for these small lengths, which did not exceed 1 centimetre at each end, the part of the wire measured was at the temperature of the inner tube. The marks were observed in the microscopes, and no reading was taken until a short time after the wire had ceased expanding, the temperature being taken by a platinum thermometer, as recommended by Gray, Blyth, and Dunlop.† The results of these experiments gave in every case graphs which were straight lines.

* *Proc. R.S.E.*, vol. xxvii., p. 343, read June 1907.

† *Proc. R.S.*, vol. lxvii., p. 180.

Again, in my first paper, the wire was put through only one cycle; but this investigation has been carried out in more detail by putting each wire through a sufficient number of cycles to bring it to the cyclically steady state. The iron and steel had to be carried through several cycles before this was accomplished, the platinum required two cycles, while the copper reached it at the end of the first.

The investigation has also been extended in another direction, on account of the totally different results obtained by Miss Noyes * in a second paper, where another series of experiments on various wires is described. In her first paper the results, generally speaking, were similar to those I described in my first paper, viz. an increase of the modulus to a maximum, and then a decrease. In her second paper, however, the graphs are straight lines when the wire was heated by a current through it, as well as when it was heated by a helix and by a non-inductive current. Now, the only difference in the conditions was that in the second case the load was much greater than in the other. It became necessary, then, to examine this, and experiments were performed on all the wires with much greater loads than in the previous experiments. My results quite confirm those of Miss Noyes, and show that, under a load approaching the elastic limit, the decrease in Young's modulus is uniform.

In those experiments in which the temperature was determined by measuring the resistance of the wire, the method is perhaps open to criticism, and may seem to stand in need of justification. The temperature coefficient of resistance had been determined in the usual way in an oil-bath when the wire was unstretched, whereas in the experiments the resistance was determined under tension. Therefore the assumption is that no appreciable difference is produced in the resistance of the wire by the load. The experiment with which I am most familiar is that described by Kelvin,† where he discusses the electrical resistance of a wire under tension. No exact quantitative results are given, but the effect is small, and, as the curves are wide apart and cut at a large angle, the assumption seems a legitimate one to make.

The results are correct to a unit in the fourth significant figure, that is, the deviation of any individual reading of a set from the mean does not exceed a unit on either the one side or the other.

When the wire was bare there was radiation, and consequently a temperature gradient in the wire. To see if any change was produced when there

* *Phys. Rev.*, vol. iii., p. 452.

† *Math. and Phys. Papers*, vol. ii., p. 298. The fourth paper of the series on "The Electro-Dynamic Qualities of Metals."

was no temperature gradient, the wire was covered with asbestos and put through a cycle of heating and cooling, but there was no difference in the results.

## Soft Iron.

A wire from a different coil, but of the same gauge as in the first experiment, was taken. The modulus was determined at the temperature of the room, and found to be $18 \cdot 14 \times 10^{11}$, which was lower than the value in the first wire. A weak current was then passed through it, which raised the temperature slightly, and this was accompanied by a decrease in the modulus. On strengthening the current the modulus rose in value, and continued to rise as the current was increased until the temperature was a little over 50° C. After the maximum had been reached there was a gradual diminution, the rate of which was fairly uniform up to a temperature of about 110° C. Beyond this the rate of fall diminished. On decreasing the current there was at first a further slight fall in the modulus, but as the temperature continued to fall a minimum was reached, and the increase that ensued went on to a temperature a little over 60° C. This maximum with the diminishing current has a lower value, and is reached at a higher temperature, than that with the increasing current. Beyond this point, as the current becomes less, the modulus falls, and finally reaches a value lower than what it had when the current was started. After cooling to the temperature of the room, the modulus had a higher value than before any current was passed through the wire. This was the behaviour of the wire during the first cycle, and these results are quite the same as those described in my former paper.

As the wire had not returned to the same state as when the current was started, the cycle was repeated and readings taken as before. There were slight changes, the value being always higher than at the corresponding temperature in the first cycle. The value at a temperature only slightly above that of the room was still lower than what it was with a commencing current at the same temperature, and it was not till the fifth cycle had been completed that the steady state was reached.

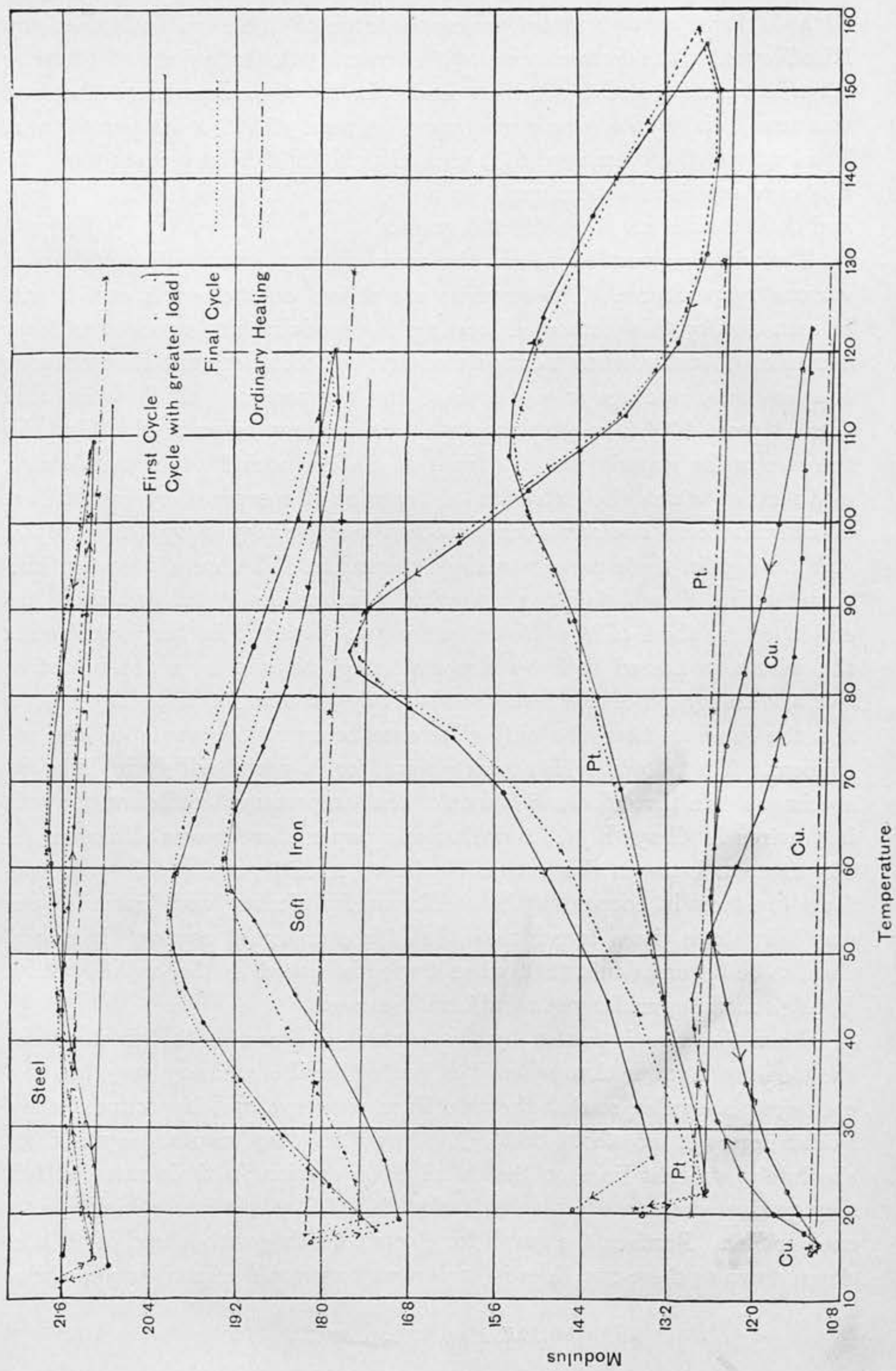
After the steady state was reached, the value was higher than at the same temperature in any of the preceding cycles. It is to be noted that the change is greatest with a diminishing current when the temperature is below 50° C. The same effect, viz. an increase in the modulus, was found when no current was being carried by the wire. The value was higher after the cyclically steady state had been reached than under the same conditions in any of the preceding cycles.

As I have already stated, in consequence of the results obtained by Miss Noyes, it was deemed necessary to examine the behaviour of the wire when it was subjected to a greater load. In the first experiment the load was small, viz. ·8 kilo, which was equal to nearly 14·62 kilos per sq. mm. The load was then increased to 2 kilos, that is, 36·54 kilos per sq. mm. In this case my results were quite in agreement with those of Miss Noyes, and these results are shown in the graph.

The wire was next heated in the ordinary way, and readings taken at various temperatures. These results are shown on the graph, and it will be seen that by this method of heating the modulus undergoes a uniform decrease. Usually, when Young's modulus has been determined at different temperatures, readings were taken at the temperature of the room and then at about 100° C., no intermediate temperatures being used. This was the case in the experiments described in Shakespear's* paper on Young's modulus, in which the extension of the wire is measured by the method of interference. The same temperatures were employed by Gray, Blyth, and Dunlop in their paper already referred to. The only investigations with which I am familiar in which intermediate temperatures are employed are those of Miss Noyes in her two papers. In her experiments the wire was heated both by a magnetising coil and by a non-inductive coil, and the graph of the results was always a straight line. My results are the same as hers, the only difference being in the value of the coefficient. That, however, is a minor point, for it varies widely in different specimens. In three determinations of the temperature coefficient for soft iron wires in Gray, Blyth, and Dunlop's paper there was a difference of 33 per cent. between the extreme values. A still greater difference was found by them in copper, as the coefficient for electro hard-drawn copper was fully three times larger than that for commercial copper. It seems, then, to be beyond doubt that, when a wire is heated in the ordinary way, Young's modulus undergoes a uniform decrease.

When the wire is heated by the current and carries the greater load, the modulus is lower than when it is heated in the ordinary way, but the coefficient is smaller, so that the two lines converge, and if produced they would intersect at about 215° C. Now, the two graphs may not be absolutely straight lines, so that a slight alteration in their rates of fall may produce such an effect as to make them after meeting coincide with one another. Further, the graph for electric heating with a load of ·8 kilo slopes down to these two lines in such a way as would seem to make them

* *Phil. Mag.*, 1899, p. 539.


First Cycle
Cycle with greater load
Final Cycle
Ordinary Heating
Steel
Soft Iron
Pt.
Pt.
Pt
Cu.
Cu.
Cu.
21·6
20·4
19·2
18·0
16·8
15·6
14·4
13·2
12·0
10·8
Modulus
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
Temperature

meet; it, too, therefore, may coincide with the other graphs, in which case all three would ultimately coincide, and there would be only one value for the modulus, no matter what the method of heating be, or the load within the limit of elasticity. It would be of interest to find this out, but the current at my disposal was not powerful enough to heat the wire to the necessary temperature.

## Soft Iron Wire.

Length = 97·92 cms.
Area of cross-section = ·0005474 sq. cms.
Elongation weight = 500 grams.
Total load on wire = 800 „
Load per sq. mm. = 14·62 kilos.

Table I.—First Cycle.

| No. | Temp. | Elongation for 500 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 1 | 16°·5 C. | ·04839 cm. | 6 | $18·14 \times 10^{11}$ |
| 2 | 18·8 | ·05090 | 8 | 17·25 |
| 3 | 23·4 | ·04905 | 8 | 17·90 |
| 4 | 29·1 | ·04736 | 8 | 18·54 |
| 5 | 35·3 | ·04592 | 8 | 19·12 |
| 6 | 42·0 | ·04465 | 9 | 19·66 |
| 7 | 45·9 | ·04412 | 8 | 19·90 |
| 8 | 50·6 | ·04377 | 8 | 20·06 |
| 9 | 54·2 | ·04368 | 8 | 20·10 |
| 10 | 59·5 | ·04387 | 9 | 20·01 |
| 11 | 65·7 | ·04438 | 7 | 19·78 |
| 12 | 74·4 | ·04519 | 6 | 19·43 |
| 13 | 85·6 | ·04638 | 8 | 18·93 |
| 14 | 100·4 | ·04795 | 8 | 18·31 |
| 15 | 110·3 | ·04880 | 8 | 17·99 |
| 16 | 120·3 | ·04932 | 8 | 17·80 |
| 17 | 114·1 | ·04938 | 8 | 17·78 |
| 18 | 105·2 | ·04909 | 7 | 17·89 |
| 19 | 92·5 | ·04838 | 8 | 18·15 |
| 20 | 80·9 | ·04754 | 8 | 18·47 |
| 21 | 74·0 | ·04670 | 9 | 18·80 |
| 22 | 66·8 | ·04576 | 8 | 19·19 |
| 23 | 61·2 | ·04544 | 6 | 19·32 |
| 24 | 57·5 | ·04566 | 7 | 19·23 |
| 25 | 53·0 | ·04635 | 8 | 18·94 |
| 26 | 45·2 | ·04780 | 8 | 18·37 |
| 27 | 39·3 | ·04899 | 8 | 17·92 |
| 28 | 32·0 | ·05034 | 5 | 17·44 |
| 29 | 25·9 | ·05125 | 8 | 17·13 |
| 30 | 19·5 | ·05186 | 8 | 16·93 |
| 31 | 16·7 | ·04828 | 8 | 18·18 |

Table II.—Final Cycle.

| No. | Temp. | Elongation for 500 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 1 | 19°·2 C. | ·05043 cm. | 8 | $17·41 \times 10^{11}$ |
| 2 | 25·3 | ·04819 | 8 | 18·22 |
| 3 | 30·9 | ·04670 | 8 | 18·80 |
| 4 | 40·1 | ·04468 | 8 | 19·65 |
| 5 | 45·4 | ·04396 | 8 | 19·97 |
| 6 | 49·3 | ·04373 | 8 | 20·08 |
| 7 | 52·5 | ·04359 | 8 | 20·14 |
| 8 | 55·0 | ·04361 | 10 | 20·13 |
| 9 | 58·6 | ·04371 | 8 | 20·09 |
| 10 | 64·7 | ·04403 | 8 | 19·94 |
| 11 | 73·4 | ·04479 | 8 | 19·60 |
| 12 | 83·1 | ·04487 | 9 | 19·12 |
| 13 | 94·2 | ·04700 | 8 | 18·68 |
| 14 | 104·5 | ·04801 | 8 | 18·29 |
| 15 | 112·0 | ·04863 | 8 | 18·04 |
| 16 | 119·7 | ·04910 | 8 | 17·88 |
| 17 | 114·9 | ·04918 | 6 | 17·86 |
| 18 | 108·3 | ·04891 | 8 | 17·95 |
| 19 | 99·8 | ·04832 | 8 | 18·17 |
| 20 | 90·6 | ·04751 | 8 | 18·48 |
| 21 | 81·1 | ·04674 | 8 | 18·78 |
| 22 | 71·5 | ·04594 | 9 | 19·11 |
| 23 | 65·2 | ·04554 | 8 | 19·28 |
| 24 | 61·0 | ·04537 | 8 | 19·35 |
| 25 | 57·4 | ·04547 | 8 | 19·31 |
| 26 | 50·9 | ·04614 | 6 | 19·03 |
| 27 | 41·5 | ·04751 | 9 | 18·48 |
| 28 | 33·8 | ·04870 | 8 | 18·03 |
| 29 | 27·1 | ·04962 | 8 | 17·69 |
| 30 | 23·7 | ·05011 | 8 | 17·52 |
| 31 | 19·2 | ·05043 | 8 | 17·41 |
| 32 | 17·6 | ·04815 | 8 | 18·23 |

Total load = 2·0 kilos.
= 36·54 kilos per sq. mm.

TABLE III.

| No. | Temp. | Elongation for 500 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 1 | 18°·8 C. | ·05020 cm. | 8 | $17{\cdot}49 \times 10^{11}$ |
| 2 | 26·3 | ·05029 | 8 | 17·46 |
| 3 | 35·5 | ·05037 | 8 | 17·43 |
| 4 | 42·9 | ·05034 | 8 | 17·44 |
| 5 | 50·8 | ·05052 | 7 | 17·38 |
| 6 | 57·4 | ·05043 | 8 | 17·41 |
| 7 | 65·7 | ·05052 | 8 | 17·38 |
| 8 | 76·2 | ·05058 | 6 | 17·36 |
| 9 | 89·6 | ·05082 | 6 | 17·28 |
| 10 | 100·3 | ·05070 | 8 | 17·32 |
| 11 | 116·5 | ·05091 | 8 | 17·25 |
| 12 | 108·5 | ·05094 | 8 | 17·24 |
| 13 | 97·7 | ·05076 | 8 | 17·30 |
| 14 | 84·1 | ·05064 | 10 | 17·34 |
| 15 | 71·4 | ·05064 | 8 | 17·34 |
| 16 | 60·3 | ·05043 | 8 | 17·41 |
| 17 | 51·9 | ·05049 | 9 | 17·39 |
| 18 | 43·2 | ·05037 | 8 | 17·43 |
| 19 | 36·8 | ·05026 | 8 | 17·47 |
| 20 | 29·5 | ·05034 | 8 | 17·44 |
| 21 | 24·1 | ·05031 | 8 | 17·45 |
| 22 | 19·0 | ·05023 | 8 | 17·48 |

ORDINARY HEATING.

Length = 94·60 cms.
Load = 1·2 kilos.

TABLE IV.

| No. | Temp. | Elongation for 500 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 1 | 17°·5 C. | ·04644 cm. | 6 | $18{\cdot}22 \times 10^{11}$ |
| 2 | 35·0 | ·04680 | 5 | 18·08 |
| 3 | 78·0 | ·04734 | 6 | 17·87 |
| 4 | 100·0 | ·04777 | 7 | 17·71 |
| 5 | 129·0 | ·04829 | 6 | 17·56 |

## Steel Wire.

With this wire the method of procedure was the same as with the soft iron. The modulus was first determined at the temperature of the room before any current had been passed through the wire, and the value was found to be $21{\cdot}60 \times 10^{11}$. On passing a weak current the modulus was lower than before any current was passed, but on increasing the current slightly the modulus rose in value. With a further increase in the current it continued also to rise until a maximum was attained at about 45° C., and then fell regularly as the temperature rose.

When the current was diminished the modulus increased, and that, too, more rapidly than it had fallen with the increasing current. The maximum was reached at about 62° C., and this was the highest value throughout all the experiments on this wire. As the temperature continued to fall the modulus diminished, and came finally to a lower value than it had when the current was started. On allowing the wire to cool to the temperature of the room, the value was a little higher than it was initially.

Since the modulus towards the end of the cycle did not have the same values as it had at these temperatures at the beginning, the cycle of operations was repeated, and the values were found to be a little higher than in the first. This increase obtained all through, and there was also a slight increase in the value after the wire had cooled to the temperature of the room, compared with that at the corresponding stage of the first cycle. In all, four cycles had to be completed before the cyclically steady state was reached. When allowed to cool to the temperature of the room, the modulus had a higher value than in any of the previous determinations without a current. The effect, then, is to produce a permanent increase.

In accordance with the plan on which the experiments were carried out, the wire was next loaded with 2·2 kilos, that is, about 46·6 kilos per sq. mm., and heated by passing a current through it, with the results as shown in the graph. With this load on the wire the decrease is uniform, for the graph is a straight line.

The same wire was then heated in the ordinary way in the double-walled tube, the graph being again a straight line.

We see that the results for steel are very much the same as those for soft iron, the most important respect in which they differ being that with the decreasing current the soft iron has a lower modulus than with the increasing, whereas in steel it is at first higher with the decreasing current. Again, as with the soft iron, the temperature coefficient for ordinary heating is greater than that for heating by the current when the load is 2·2 kilos, and if these lines were produced they would intersect at about 240° C. In this case, also, the graph for the electric heating with a load of ·8 kilo approaches the other two graphs, and it is again possible that the three may ultimately all coincide.

### Steel Wire.

| | |
|---|---|
| Length | = 98·45 cms. |
| Area of cross-section | = ·0004714 sq. cm. |
| Elongation weight | = 500 grams. |
| Total load on wire | = 800 ,, |
| Load per sq. mm. | = 16·96 kilos. |

Table I.—First Cycle.

| No. | Temp. | Elongation for 500 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 1 | 12°·0 C. | ·04745 cm. | 8 | $21·60 \times 10^{11}$ |
| 2 | 14·1 | ·04839 | 8 | 21·18 |
| 3 | 20·3 | ·04803 | 8 | 21·34 |
| 4 | 28·4 | ·04776 | 8 | 21·46 |
| 5 | 33·5 | ·04760 | 8 | 21·53 |
| 6 | 40·0 | ·04747 | 8 | 21·59 |
| 7 | 43·2 | ·04745 | 10 | 21·60 |
| 8 | 48·8 | ·04749 | 8 | 21·58 |
| 9 | 55·4 | ·04760 | 8 | 21·53 |
| 10 | 64·7 | ·04778 | 6 | 21·45 |
| 11 | 76·1 | ·04798 | 8 | 21·36 |
| 12 | 89·5 | ·04818 | 8 | 21·27 |
| 13 | 100·9 | ·04830 | 7 | 21·22 |
| 14 | 109·2 | ·04837 | 8 | 21·19 |
| 15 | 106·0 | ·04830 | 7 | 21·22 |
| 16 | 97·3 | ·04800 | 8 | 21·35 |
| 17 | 90·4 | ·04773 | 6 | 21·47 |
| 18 | 80·6 | ·04740 | 8 | 21·62 |
| 19 | 71·7 | ·04716 | 10 | 21·75 |
| 20 | 64·0 | ·04701 | 8 | 21·80 |
| 21 | 62·1 | ·04699 | 9 | 21·81 |
| 22 | 60·2 | ·04702 | 8 | 21·79 |
| 23 | 55·4 | ·04710 | 8 | 21·76 |
| 24 | 45·7 | ·04742 | 8 | 21·61 |
| 25 | 38·9 | ·04760 | 8 | 21·48 |
| 26 | 30·5 | ·04818 | 8 | 21·27 |
| 27 | 24·8 | ·04848 | 6 | 21·15 |
| 28 | 20·0 | ·04867 | 7 | 21·06 |
| 29 | 14·0 | ·04880 | 8 | 20·98 |
| 30 | 12·5 | ·04740 | 8 | 21·62 |

Table II.—Final Cycle.

| No. | Temp. | Elongation for 500 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 1 | 12°·6 C. | ·04729 cm. | 8 | $21·67 \times 10^{11}$ |
| 2 | 14·3 | ·04835 | 8 | 21·20 |
| 3 | 19·8 | ·04800 | 8 | 21·35 |
| 4 | 25·1 | ·04778 | 8 | 21·45 |
| 5 | 31·5 | ·04758 | 8 | 21·54 |
| 6 | 35·0 | ·04749 | 8 | 21·58 |
| 7 | 37·7 | ·04745 | 8 | 21·60 |
| 8 | 40·2 | ·04743 | 8 | 21·61 |
| 9 | 43·8 | ·04743 | 8 | 21·61 |
| 10 | 47·3 | ·04745 | 7 | 21·60 |
| 11 | 54·9 | ·04756 | 8 | 21·55 |
| 12 | 63·0 | ·04769 | 6 | 21·49 |
| 13 | 72·5 | ·04784 | 8 | 21·42 |
| 14 | 82·7 | ·04803 | 9 | 21·34 |
| 15 | 89·4 | ·04814 | 8 | 21·29 |
| 16 | 96·0 | ·04821 | 8 | 21·26 |
| 17 | 100·9 | ·04827 | 6 | 21·23 |
| 18 | 106·0 | ·04832 | 8 | 21·21 |
| 19 | 109·1 | ·04835 | 7 | 21·20 |
| 20 | 105·3 | ·04825 | 9 | 21·24 |
| 21 | 99·6 | ·04803 | 8 | 21·33 |
| 22 | 91·5 | ·04771 | 6 | 21·48 |
| 23 | 82·2 | ·04738 | 7 | 21·63 |
| 24 | 75·7 | ·04714 | 8 | 21·74 |
| 25 | 69·8 | ·04702 | 8 | 21·79 |
| 26 | 65·4 | ·04699 | 9 | 21·81 |
| 27 | 62·0 | ·04697 | 10 | 21·82 |
| 28 | 58·1 | ·04699 | 9 | 21·81 |
| 29 | 52·5 | ·04710 | 8 | 21·76 |
| 30 | 45·3 | ·04736 | 8 | 21·64 |
| 31 | 36·9 | ·04767 | 6 | 21·50 |
| 32 | 30·2 | ·04794 | 7 | 21·38 |
| 33 | 25·6 | ·04809 | 8 | 21·31 |
| 34 | 19·7 | ·04825 | 8 | 21·24 |
| 35 | 14·3 | ·04835 | 8 | 21·20 |
| 36 | 12·6 | ·04729 | 9 | 21·67 |

Total load = 2·2 kilos.
= 46·6 kilos per sq. mm.

TABLE III.

| No. | Temp. | Elongation for 500 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 1 | 13°·8 C. | ·04830 cm. | 5 | $21·22 \times 10^{11}$ |
| 2 | 22·5 | ·04834 | 6 | 21·20 |
| 3 | 30·9 | ·04844 | 6 | 21·16 |
| 4 | 41·2 | ·04848 | 6 | 21·14 |
| 5 | 52·3 | ·04856 | 6 | 21·10 |
| 6 | 62·7 | ·04862 | 7 | 21·07 |
| 7 | 74·1 | ·04868 | 6 | 21·04 |
| 8 | 83·6 | ·04876 | 6 | 21·00 |
| 9 | 95·9 | ·04882 | 6 | 20·97 |
| 10 | 104·0 | ·04890 | 5 | 20·93 |
| 11 | 112·7 | ·04894 | 7 | 20·91 |
| 12 | 101·2 | ·04886 | 7 | 20·95 |
| 13 | 92·1 | ·04882 | 5 | 20·97 |
| 14 | 80·5 | ·04874 | 6 | 21·01 |
| 15 | 69·8 | ·04866 | 6 | 21·05 |
| 16 | 60·4 | ·04860 | 6 | 21·08 |
| 17 | 49·3 | ·04856 | 6 | 21·10 |
| 18 | 41·1 | ·04850 | 7 | 21·13 |
| 19 | 29·9 | ·04842 | 7 | 21·17 |
| 20 | 23·2 | ·04836 | 5 | 21·19 |
| 21 | 13·8 | ·04830 | 6 | 21·22 |

ORDINARY HEATING.

Load = 1·3 kilos.
Length = 94·90 cms.

TABLE IV.

| No. | Temp. | Elongation for 500 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 1 | 15°·0 C. | ·04571 cm. | 6 | $21·61 \times 10^{11}$ |
| 2 | 35·0 | ·04591 | 7 | 21·52 |
| 3 | 78·0 | ·04638 | 6 | 21·30 |
| 4 | 100·0 | ·04660 | 6 | 21·20 |
| 5 | 129·0 | ·04703 | 6 | 21·06 |

## Copper.

A piece of wire of the same gauge was used as in the first experiment. First, a measurement at the temperature of the room was made, the value being $11{\cdot}21 \times 10^{11}$. On strengthening the current there was a rapid increase in the modulus, the maximum being at about 45° C. There was then a diminution, somewhat rapid at first, but the rate of which gradually fell away, until at about 95° C. it had become fairly uniform. When the current was diminished there was an increase in the modulus, which continued until a maximum was attained at about 57° C. This maximum was lower than that with the increasing current, and the value fell gradually until it was the same as when the current started. In this case, then, the cyclically steady state was reached in the course of the first cycle. On cooling to the temperature of the room, the modulus had a value somewhat higher than its original value before any current was passed through the wire, so that there was a permanent increase produced by the current.

In this experiment the wire was loaded with ·8 kilo, that is, 12·8 kilos per sq. mm. The wire was then loaded with 1·6 kilos, that is, 25·6 kilos per sq. mm., and the graph was a straight line, the values being as shown in the diagram.

The same wire was next heated in the ordinary way, as in the other two cases, and here again the graph was a straight line.

The results for copper are, generally speaking, similar to those for iron and steel, the differences being in degree rather than in kind. For example, the fall in the modulus from the value it had before any current was passed to its value when there was a weak current, also the rise in the modulus at the end of the cycle after the wire had cooled to the temperature of the room, were both smaller than the corresponding changes with iron and steel. Again, the difference between the values obtained by the ordinary heating and the electric heating with the wire under greater tension is less than in the two preceding cases.

When the two straight lines are produced they intersect at about 180° C.; and since the graph for electric heating with a load of ·8 kilo has become at 120° C. nearly a straight line, in which the rate of fall is greater than in the other graphs, they will all finally intersect one another. Therefore it is possible in this case also that the three may ultimately coincide.

COPPER.

Length = 97·83 cms.
Area of cross-section = ·0006026 sq. cm.
Elongation weight = 300 grams.
Total load on wire = 800 „
Load per sq. mm. = 12·8 kilos.

TABLE I.

| No. | Temp. | Elongation for 300 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 1 | 15°·2 C. | ·04264 cm. | 8 | $11·21 \times 10^{11}$ |
| 2 | 16·3 | ·04306 | 8 | 11·10 |
| 3 | 17·5 | ·04230 | 8 | 11·30 |
| 4 | 20·0 | ·04082 | 8 | 11·71 |
| 5 | 24·8 | ·03934 | 8 | 12·15 |
| 6 | 30·6 | ·03830 | 8 | 12·48 |
| 7 | 36·7 | ·03766 | 8 | 12·69 |
| 8 | 41·4 | ·03734 | 8 | 12·80 |
| 9 | 44·8 | ·03731 | 8 | 12·81 |
| 10 | 47·5 | ·03746 | 8 | 12·76 |
| 11 | 52·0 | ·03796 | 7 | 12·59 |
| 12 | 60·1 | ·03925 | 7 | 12·18 |
| 13 | 65·3 | ·04020 | 7 | 11·89 |
| 14 | 70·9 | ·04086 | 6 | 11·70 |
| 15 | 77·7 | ·04138 | 8 | 11·55 |
| 16 | 84·2 | ·04178 | 8 | 11·44 |
| 17 | 95·6 | ·04215 | 8 | 11·34 |
| 18 | 106·1 | ·04238 | 8 | 11·28 |
| 19 | 115·5 | ·04267 | 8 | 11·22 |
| 20 | 122·3 | ·04277 | 9 | 11·18 |
| 21 | 116·2 | ·04225 | 8 | 11·29 |
| 22 | 110·0 | ·04193 | 8 | 11·40 |
| 23 | 99·8 | ·04103 | 8 | 11·65 |
| 24 | 91·0 | ·04026 | 8 | 11·87 |
| 25 | 82·3 | ·03944 | 8 | 12·12 |
| 26 | 74·1 | ·03858 | 8 | 12·39 |
| 27 | 67·4 | ·03825 | 8 | 12·50 |
| 28 | 62·5 | ·03812 | 7 | 12·54 |
| 29 | 56·7 | ·03809 | 7 | 12·55 |
| 30 | 51·5 | ·03822 | 8 | 12·51 |
| 31 | 44·2 | ·03861 | 9 | 12·38 |
| 32 | 34·9 | ·03955 | 7 | 12·09 |
| 33 | 27·6 | ·04051 | 8 | 11·80 |
| 34 | 22·8 | ·04150 | 8 | 11·52 |
| 35 | 20·0 | ·04212 | 8 | 11·35 |
| 36 | 16·3 | ·04306 | 8 | 11·10 |
| 37 | 15·8 | ·04249 | 6 | 11·25 |

Total load = 1·6 kilos.
= 25·6 kilos per sq. mm.

TABLE II.

| No. | Temp. | Elongation for 300 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 1 | 18°·7 C. | ·04295 cm. | 8 | $11{\cdot}13 \times 10^{11}$ |
| 2 | 26·4 | ·04306 | 8 | 11·10 |
| 3 | 35·3 | ·04312 | 8 | 11·09 |
| 4 | 43·9 | ·04327 | 6 | 11·05 |
| 5 | 55·1 | ·04341 | 6 | 11·01 |
| 6 | 64·5 | ·04341 | 8 | 11·01 |
| 7 | 72·2 | ·04356 | 7 | 10·97 |
| 8 | 87·0 | ·04368 | 8 | 10·94 |
| 9 | 99·3 | ·04377 | 7 | 10·92 |
| 10 | 106·1 | ·04385 | 8 | 10·90 |
| 11 | 113·8 | ·04396 | 8 | 10·87 |
| 12 | 122·2 | ·04405 | 8 | 10·85 |
| 13 | 111·4 | ·04388 | 8 | 10·89 |
| 14 | 102·5 | ·04385 | 9 | 10·90 |
| 15 | 96·7 | ·04385 | 8 | 10·90 |
| 16 | 85·3 | ·04372 | 8 | 10·93 |
| 17 | 74·8 | ·04348 | 8 | 10·99 |
| 18 | 63·7 | ·04345 | 7 | 11·00 |
| 19 | 51·2 | ·04339 | 6 | 11·02 |
| 20 | 45·6 | ·04319 | 8 | 11·07 |
| 21 | 36·5 | ·04315 | 8 | 11·08 |
| 22 | 29·1 | ·04303 | 8 | 11·11 |
| 23 | 22·6 | ·04306 | 8 | 11·10 |
| 24 | 18·7 | ·04295 | 8 | 11·13 |

ORDINARY HEATING.

Length = 94·72 cms.
Load = ·8 kilo.

TABLE III.

| No. | Temp. | Elongation for 300 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 1 | 15°·7 C. | ·04118 cm. | 6 | $11{\cdot}24 \times 10^{11}$ |
| 2 | 35·0 | ·04144 | 6 | 11·17 |
| 3 | 77·8 | ·04196 | 6 | 11·03 |
| 4 | 100·0 | ·04217 | 6 | 10·97 |
| 5 | 129·6 | ·04257 | 6 | 10·87 |

### Platinum.

In this case the wire was that used in the first experiment, and the first cycle is, with a few trifling exceptions, practically identical with that experiment. When the modulus was determined at the temperature of the room, the value was $13 \cdot 55 \times 10^{11}$, and then when a weak current was passed the value fell. Here there is a difference from the first experiment, for in it the first effect of the current was to increase the modulus. In the two experiments, however, the modulus had the same value when the current was weak. Now, in the first experiment the effect of the cycle was to increase the modulus when the wire had cooled to the temperature of the room, so that some of this effect must have remained in the wire; for, while the value is lower than the final determination at the room temperature in the first experiment, it is higher than the initial value.

The modulus was then determined at various temperatures with a gradually increasing current, with the results as shown in the graph. It will be seen how closely this agrees with the first experiment. The maximum is at about 108° C., and the modulus falls more rapidly than it rose. On decreasing the current there is at first a fall, then a rise, which at about 125° C. increases in rate until a maximum is reached at about 85° C. The subsequent fall is at first fairly rapid, then the rate gradually diminishes down to the lowest temperature at which a reading was taken. After cooling to the temperature of the room, there was an increase in the modulus.

As the wire had not returned to its original state, the cycle was repeated, and the results were as shown in the graph. With an increasing current the value was a little greater than at the corresponding stage in the preceding cycle until a temperature of about 107° C. was reached, at which point the graphs intersect. Beyond this, until a temperature of about 143° C. was reached, the second cycle was lower than the preceding. At this point they crossed again, and the second did not diminish so rapidly as the first. On decreasing the current there was again a fall, but the values with the diminishing current were still higher than those with the preceding cycle. The two graphs then run closely side by side until near the maximum with a decreasing current, when it was found to be lower than that which preceded it. Beyond this point the rate of fall is at first almost the same as previously; then, at about 77° C., the rate of decrease becomes greater than at the same stage, and continues increasing until, on being brought back to the temperature produced by a weak current at the beginning of this cycle, it was found that the cyclically steady state had been reached. On allowing the wire to cool to the temperature of the room, the modulus was higher than at the beginning of these two cycles, but it was lower than at the corresponding stage at the end of the first experiment.

The wire was next loaded with 2·2 kilos, that is, 29 kilos per sq. mm., with the results shown in the graph.

Finally, the wire was heated in the ordinary way, and the results of this experiment are also recorded in the graph.

With the platinum, as with the other three wires, the value with the ordinary heating was higher than when it was heated by the current with the greater load on. When produced, the lines intersect at about 240° C.; and again, from the slope of the curve, with the electric heating and smaller weight, we see that the graphs will all ultimately intersect. It is again possible also to suppose that all the three may finally coincide, and there be at last only one value for the modulus.

[Table

## Platinum.

Length = 62·12 cms.
Area of cross-section = ·0007548 sq. cms.
Elongation weight = 300 grams.
Total load on wire = 800 „
Load per sq. mm. = 10·56 kilos.

Table I.—First Cycle.

| No. | Temp. | Elongation for 300 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 1 | 20·0° C. | ·01788 cm. | 8 | $13{\cdot}55 \times 10^{11}$ |
| 2 | 22·8 | ·01918 | 8 | 12·63 |
| 3 | 30·0 | ·01897 | 8 | 12·74 |
| 4 | 45·1 | ·01829 | 6 | 13·25 |
| 5 | 59·3 | ·01786 | 6 | 13·57 |
| 6 | 68·9 | ·01749 | 8 | 13·85 |
| 7 | 79·6 | ·01709 | 8 | 14·18 |
| 8 | 88·5 | ·01671 | 9 | 14·50 |
| 9 | 94·2 | ·01642 | 10 | 14·76 |
| 10 | 101·5 | ·01601 | 8 | 15·14 |
| 11 | 107·7 | ·01573 | 8 | 15·41 |
| 12 | 114·0 | ·01583 | 8 | 15·31 |
| 13 | 123·8 | ·01626 | 8 | 14·90 |
| 14 | 135·6 | ·01704 | 8 | 14·22 |
| 15 | 145·4 | ·01802 | 8 | 13·45 |
| 16 | 155·2 | ·01918 | 8 | 12·63 |
| 17 | 150·0 | ·01948 | 8 | 12·44 |
| 18 | 142·6 | ·01943 | 8 | 12·47 |
| 19 | 131·1 | ·01920 | 8 | 12·62 |
| 20 | 120·7 | ·01858 | 8 | 13·04 |
| 21 | 112·3 | ·01759 | 6 | 13·79 |
| 22 | 108·2 | ·01682 | 9 | 14·41 |
| 23 | 103·5 | ·01602 | 7 | 15·13 |
| 24 | 97·6 | ·01505 | 8 | 16·10 |
| 25 | 89·9 | ·01399 | 8 | 17·32 |
| 26 | 85·1 | ·01376 | 8 | 17·61 |
| 27 | 82·6 | ·01386 | 8 | 17·48 |
| 28 | 78·2 | ·01446 | 8 | 16·75 |
| 29 | 74·9 | ·01497 | 7 | 16·19 |
| 30 | 68·8 | ·01563 | 6 | 15·50 |
| 31 | 55·7 | ·01656 | 8 | 14·63 |
| 32 | 44·2 | ·01731 | 9 | 14·00 |
| 33 | 32·3 | ·01780 | 8 | 13·61 |
| 34 | 26·5 | ·01796 | 8 | 13·49 |
| 35 | 23·2 | ·01802 | 8 | 13·45 |
| 36 | 20·3 | ·01669 | 8 | 14·52 |

Table II.—Final Cycle.

| No. | Temp. | Elongation for 300 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 1 | 22°·3 C. | ·01912 cm. | 8 | $12·67 \times 10^{11}$ |
| 2 | 28·9 | ·01890 | 8 | 12·82 |
| 3 | 40·5 | ·01843 | 8 | 13·15 |
| 4 | 49·7 | ·01812 | 8 | 13·37 |
| 5 | 57·2 | ·01784 | 8 | 13·58 |
| 6 | 69·8 | ·01741 | 8 | 13·92 |
| 7 | 77·5 | ·01710 | 8 | 14·17 |
| 8 | 88·4 | ·01663 | 8 | 14·57 |
| 9 | 100·3 | ·01607 | 8 | 15·08 |
| 10 | 105·6 | ·01587 | 8 | 15·27 |
| 11 | 110·0 | ·01577 | 9 | 15·37 |
| 12 | 113·4 | ·01589 | 8 | 15·25 |
| 13 | 120·9 | ·01617 | 8 | 14·98 |
| 14 | 126·2 | ·01654 | 10 | 14·65 |
| 15 | 133·5 | ·01690 | 9 | 14·34 |
| 16 | 140·1 | ·01748 | 9 | 13·86 |
| 17 | 146·2 | ·01798 | 8 | 13·48 |
| 18 | 157·0 | ·01900 | 8 | 12·75 |
| 19 | 149·9 | ·01940 | 8 | 12·49 |
| 20 | 141·7 | ·01938 | 8 | 12·50 |
| 21 | 130·4 | ·01906 | 10 | 12·71 |
| 22 | 124·3 | ·01874 | 8 | 12·93 |
| 23 | 117·5 | ·01819 | 7 | 13·32 |
| 24 | 112·0 | ·01749 | 8 | 13·85 |
| 25 | 104·6 | ·01611 | 9 | 15·04 |
| 26 | 98·4 | ·01502 | 8 | 16·13 |
| 27 | 93·1 | ·01417 | 8 | 17·10 |
| 28 | 89·8 | ·01391 | 8 | 17·42 |
| 29 | 87·3 | ·01380 | 8 | 17·56 |
| 30 | 84·1 | ·01386 | 8 | 17·48 |
| 31 | 81·5 | ·01405 | 8 | 17·25 |
| 32 | 75·9 | ·01493 | 8 | 16·16 |
| 33 | 71·2 | ·01561 | 9 | 15·52 |
| 34 | 65·0 | ·01623 | 7 | 14·93 |
| 35 | 56·8 | ·01679 | 6 | 14·43 |
| 36 | 50·3 | ·01720 | 6 | 14·09 |
| 37 | 41·2 | ·01787 | 7 | 13·56 |
| 38 | 30·9 | ·01854 | 8 | 13·07 |
| 39 | 25·6 | ·01890 | 8 | 12·82 |
| 40 | 22·3 | ·01912 | 8 | 12·67 |
| 41 | 20·7 | ·01779 | 8 | 13·62 |

Total load = 2·2 kilos.
= 29 kilos per sq. mm.

TABLE III.

| No. | Temp. | Elongation for 300 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 1 | 23°·0 C. | ·01914 cm. | 8 | $12·67 \times 10^{11}$ |
| 2 | 30·2 | ·01917 | 8 | 12·65 |
| 3 | 42·6 | ·01922 | 7 | 12·62 |
| 4 | 49·5 | ·01928 | 7 | 12·58 |
| 5 | 60·1 | ·01940 | 8 | 12·50 |
| 6 | 71·9 | ·01940 | 8 | 12·50 |
| 7 | 85·0 | ·01944 | 9 | 12·48 |
| 8 | 99·7 | ·01951 | 10 | 12·43 |
| 9 | 112·4 | ·01969 | 8 | 12·32 |
| 10 | 126·3 | ·01974 | 8 | 12·29 |
| 11 | 142·6 | ·01980 | 9 | 12·25 |
| 12 | 157·8 | ·01993 | 8 | 12·17 |
| 13 | 151·5 | ·01983 | 8 | 12·23 |
| 14 | 138·4 | ·01985 | 8 | 12·22 |
| 15 | 125·2 | ·01972 | 8 | 12·28 |
| 16 | 110·9 | ·01970 | 9 | 12·31 |
| 17 | 100·6 | ·01966 | 8 | 12·34 |
| 18 | 87·1 | ·01942 | 10 | 12·49 |
| 19 | 71·3 | ·01942 | 7 | 12·49 |
| 20 | 57·4 | ·01934 | 8 | 12·54 |
| 21 | 45·0 | ·01925 | 6 | 12·60 |
| 22 | 31·7 | ·01922 | 7 | 12·62 |
| 23 | 23·5 | ·01913 | 8 | 12·68 |

ORDINARY HEATING.

Load = 1·2 kilos.
Length = 62·23 cms.

TABLE IV.

| No. | Temp. | Elongation for 300 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 1 | 20°·1 C. | ·01876 cm. | 5 | $12·83 \times 10^{11}$ |
| 2 | 35·0 | ·01899 | 6 | 12·78 |
| 3 | 78·0 | ·01929 | 6 | 12·58 |
| 4 | 100·0 | ·01945 | 6 | 12·48 |
| 5 | 129·8 | ·01967 | 6 | 12·34 |

## Discussion of Results.

In this paper, as already stated, the new results are—the reaching of the cyclically steady state with a small load, the effect when the load is increased, and the heating by the ordinary method.

With the copper the steady state was reached during the first cycle, but with the other three more than one cycle of operations had to be completed before this was accomplished. In all four, the heating by the ordinary method gave values that were a little higher than those by the electric heating with the greater load on, but in all cases the temperature coefficient of decrease of modulus was greater with the ordinary heating than with the other. This, of course, means that at some temperature, if the coefficients do not alter, the lines will intersect. Again, the modulus with the electric heating and smaller weight had in all cases settled down to a fairly uniform rate of decrease, these rates being such that it seems probable that all the graphs would intersect, but the current at my disposal was not sufficient to heat the wires to the temperature necessary to test this. Now, the straight-line graphs are inclined, in each case, to one another at a small angle; and quite a slight change in the coefficients would be sufficient to produce such a change in the slope of the lines, for the coefficients may not be absolutely constant, that after meeting they coincide, and then the values by the two methods of heating would be the same. In all cases, too, it might be that the same would be true of the modulus when the wire is heated by the current and loaded with the smaller weight.

There has not been much investigation of the effect of a current through a wire, that is, of a circular magnetic field, on elasticity, but there has been a good deal of research on the effect of a longitudinal field.

In a paper by Stevens and Dorsay,* the effect of a longitudinal field on Young's modulus is investigated. The method was that of flexure, a mirror being attached to the middle of the rod, and the deflections read by the movements of interference bands. The apparatus was arranged so that the rod was not heated. It passed through an inner tube, in the annular space surrounding this tube a current of water at a constant temperature was kept flowing, and on the outside of this the coil was wound. As the temperature of the rod did not rise, their results give the effect of the magnetic field alone.

In their experiments, which were performed on steel and wrought iron,

* *Phys. Rev.*, vol. ix., p. 116.

the load was small, being in some cases ·5 kilo, and in others 1 kilo, and the smaller of these is less than the total load used in any of my experiments. They found that in all cases there was an increase in the modulus. Since the loads were small, the results can be compared with my first set of experiments on each wire, and it is to be noted that there is agreement between them, viz. at the beginning of my experiments, and all through theirs, an increase in the modulus was obtained.

In a second paper Stevens * examined the effect of a longitudinal field on rigidity, in which the same apparatus was used. In summing up his results he makes the following statements:—

I. Magnetisation of an iron or steel rod increases the torsional elasticity.

II. The effect is greater in iron than in steel.

III. Increase in elasticity varies with the length of the rod.

IV. Distinct agreement with results of the experiments on the flexure of rods.

It is of importance to note that in the experiments on rigidity the rods were subjected to different couples, and that the increase was greater when the stress was smaller. This result is altogether in accordance with those I obtained, for in all cases I got a decrease in the modulus when the load was increased. Now, Young's modulus depends on the rigidity, and we may assume that the one will vary with the other, and that those conditions which produce a change in the rigidity will also cause a change in the modulus. There is, therefore, distinct agreement between these two sets of experiments and my own.

I. An increase in magnetisation produces an increase in elasticity.

II. When the metal is subjected to various stresses, the modulus is lowest when the stress is greatest.

This agreement, however, does not hold in every respect, for in one point their results differ from mine, viz. that within the range of their experiments there is no appearance of a maximum. This difference, however, can, I think, be easily accounted for if the different conditions be taken into consideration. In these the temperature of the rod was kept constant, whereas in mine it rose. But an increase in temperature produces a diminution in the modulus, and so a point must be reached at which the increase caused by the current is not sufficient to wholly counterbalance the decrease produced by the rise of temperature, and so the modulus falls.

Gray, Blyth, and Dunlop in their paper examine the effect of change of temperature on Torsional Elasticity, and find in all cases that there is a

* *Phys. Rev.*, vol. x., p. 161.

decrease. This, again, is in harmony with my results, for when I heated the wire in the ordinary way the decrease in the modulus was uniform. It also confirms my argument that those conditions which affect the rigidity of a substance produce a similar change in Young's modulus. Since, then, there is a diminution both in the rigidity and in Young's modulus when the substance is heated in the ordinary way, it is to be expected that, since an increase in the magnetic field produces an increase in the rigidity, it will have the same effect on Young's modulus.

There are other papers dealing with the effects of temperature and magnetic field on elasticity, among which may be cited those of Wertheim,* Pisati,† Katzenelsohn,‡ Hopkinson and Roger,§ Day,|| and Hopkinson.¶ The first three deal with the effect of temperature on the modulus; they all employ the ordinary method of heating. Hopkinson and Roger's paper also discusses the same question, but in their case the temperature was raised to nearly 800° C., the rod being heated in an electric furnace. Day, on the other hand, examines the effect of a magnetic field on rigidity, while Hopkinson deals with the effect of temperature on the magnetic quality of iron.

Turning again to the graphs of the electric heating with the smaller load, it seems possible that the effect may be connected with the Villari reversal. In that phenomenon, when the field is weak, a tension on the wire increases the susceptibility, but reduces it when the field is strong. Now, in my experiments there is an increase in the modulus when the current is weak and the tension moderate, so that the increase in the susceptibility and in Young's modulus seem as if they might be connected with one another. When the wire is subjected to a greater stress my experiments show that there is no such increase in the modulus, and this also is in agreement with a longitudinal stress in a magnetic field, for Ewing,** in describing the effects of longitudinal pull on iron, says, "In the case of a hard metal, where it is possible to apply a stronger pull without permanently altering the characteristics or structure of the piece, it appears that the presence of a sufficiently great amount of stress may be unfavourable to magnetisation, even in the earliest stages of the magnetising process."

On the other hand, it may be that there is no *direct* connection between

* *Ann. Chim. Phys.*, (3) vol. xii., p. 385. 1844.

† *Gaz. Chim. ital.*, vol. vii., p. 1.

‡ *Beiblätter*, xii., p. 307. 1888.

§ *Proc. R.S.*, 1905, p. 419.

|| *Am. Journ. Sc.*, vol. iii., p. 449.

¶ *Phil. Trans.*, 1889, A., p. 443.

** *Magnetic Induction in Iron*, 3rd ed., p. 209.

the two phenomena, but only a *general* connection, due to a certain similarity of conditions. In both cases a load is put on which alters the internal molecular state, and the wire tends to set into a new arrangement of molecular equilibrium. Variation of field in the one case, variation of temperature in the other, alters this state of equilibrium, and produces corresponding effects on the intensity in the one case, and on Young's modulus in the other. Now, it may be that increase of temperature at first enables the molecules to set into more stable arrangements under the load, and therefore to increase the modulus. Ultimately, however, the increase of temperature must cause it to diminish. Then, when the tension is great enough, the molecular arrangements tend to be the strongest under the conditions, and increase of temperature can only weaken them, and therefore diminish the modulus.

However, before this matter can be satisfactorily decided, it will be necessary to find out how the modulus changes as the load is gradually increased, and I hope shortly to have the honour of laying before the Society the results of experiments dealing with this part of the investigation.

(*Issued separately October* 23, 1908.)

# The Variation of Young's Modulus under an Electric Current

By

Henry Walker, M.A., B.Sc.

Part III.

# Third Paper.

The results of the investigations on four metals, -viz. steel, iron, copper, + platinum, form the subject of my two first papers. In Parts I and II the effects on the modulus when the wire was stretched with a small load + also with a much greater load, were examined. In this my third paper the investigation of these metals has been extended in several directions. The scope of the whole work has also been widened by subjecting nickel + cobalt to examination.

As the question of temperature still seemed doubtful, and as the justification given near the beginning of the second paper might not be altogether convincing, I thought it better to put the matter beyond all question. I therefore adopted the following method. Using the double-walled tube already described, the wires were passed through it & over the wheel in the same way as in the main experiments. The resistance of each wire was then determined at the temperature of the room; and at those of boiling sulphuric ether, ethyl alcohol, and amyl alcohol. Also at each of those temperatures each wire was subjected to the same loads as in the experiments in which the variations of the modulus were investigated. In all cases the difference between the resistance of the wire unstretched and stretched was small, even with the greatest load. In some cases the difference in the resistance between the stretched and unstretched wire did not exceed what would have been produced by an increase in the temperature of 0·1°C, and in no case did the increase amount to as much as would have been caused by a rise of 0·5 ·5°C. On the scale on which the curves are drawn this difference in the temperature is inappreciable, so that there is no necessity to redraw the graphs in the two preceding papers. In this paper the temperature has been determined from the graph showing the resistance of the wire when subjected to the same load as in the experiment. curves for iron and steel are

The investigation of the behaviour of soft iron, steel, copper and platinum has been continued by subjecting each wire to various loads intermediate to the two loads employed in the experiments described in the second paper. As stated there, it was found that when the load was considerably increased the modulus diminished uniformly in value, a behaviour quite different from what was found when the load was small. It became necessary, therefore, to find out how each metal behaved as the load was increased, step by step, to the maximum. ~~load~~

As the curves for iron and steel are

somewhat similar in nature to those obtained when these bodies are subjected to tensile strain in a magnetic field, the further necessity was felt of examining nickel and cobalt. These two metals give results different from each other, and also from iron, when under tensile strain in a magnetic field. Now, if there is a similarity between the variation of the modulus with magnetic field and that of intensity, it might be concluded that there was some relation between the modulus and magnetic induction.

In all preceding experiments a definite weight was put into the pan before any current was passed through the wire, then the current was gradually increased up to the maximum, and finally diminished to zero. Throughout each cycle of heating and cooling, therefore, the only change in the stress to which the wire was subjected was putting on and taking off the weight employed to produce the change of length. To vary the conditions of the experiments another method was tried, viz: to alter the load while the magnetising force was kept constant. This method of investigating the effects of stress on magnetisation is described by Ewing,* and the results are quite different from those obtained by keeping the load constant and varying the magnetic field. The idea was to find out whether, under these conditions, there would be any change in the modulus as compared with the previous conditions of experiment, and, if so, whether the

* Magnetic Induction in Iron, 3rd Ed., p. 216.

variation in the modulus was at all similar to that of the magnetic intensity. I thought this comparison would be more accurate and complete if the strength of the magnetic field were known, and I determined the mean value of the field throughout the cross section of the wire in the following manner:—

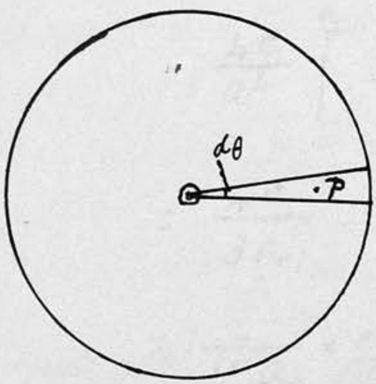



Fig. I

Let the circle of radius a represent a section of the wire, P any point at distance r from the centre O. Then the strength of the field at P, say H, is given by

$$H = \frac{2cr}{a^2}$$

where $c$ is the current in c.g.s. units. Denote the area of the cross section by $S$

$$\therefore \text{mean value of } H = \frac{1}{S}\int H\,dS$$

$$= \frac{1}{\pi a^2}\int_0^a\int_0^{2\pi} \frac{2cr^2}{a^2}\,dr\,d\theta$$

$$= \frac{4c}{a^4}\left[\frac{r^3}{3}\right]_0^a$$

$$= \frac{4c}{3a}$$

$$= \frac{2}{15a} \times \text{current}$$

when the current is in amperes.

For the investigation of cobalt I employed a rectangular strip, and determined the mean value of the field as follows.

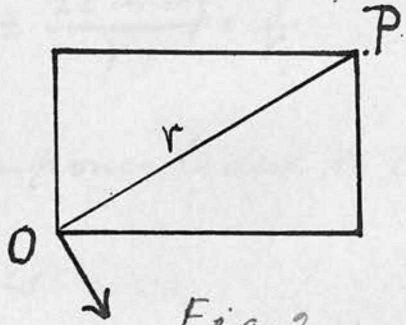



Fig. 2

Let the length and breadth of the cross section be 2a and 2b respectively, the centre being the origin. Take any point P $(x, y)$, and draw a rectangle through P similar to the strip with sides $2x$ and $2y$. Also let the elementary rectangle $dx\,dy$ be drawn having P for its centre. Suppose $i$ to be the current density, and that the current is flowing upwards from the paper. Then the current passing through the rectangle is $i\,dx\,dy$.

$\therefore$ $x$-component of magnetic force at O due to upward current $i\,dx\,dy$

$$= \frac{2i\,dx\,dy}{r} \cdot \frac{y}{r}$$

$\therefore$ total $x$-component due to current through area $xy$ is

$$I_x = 2i \int_0^x \int_0^y \frac{y}{x^2+y^2}\,dx\,dy$$

$$= i \int_0^x dx \int_0^y \frac{d(y^2)}{x^2+y^2}$$

$$= i \int_0^x dx \log \frac{x^2+y^2}{x^2}$$

Put $x = y \tan\varphi$

$$\therefore dx = y \sec^2\varphi\, d\varphi$$

$$\therefore I_x = iy \int (\log \operatorname{cosec}^2\varphi) \sec^2\varphi\, d\varphi$$

$$= -iy \int \log \sin^2\varphi\; d(\tan\varphi)$$

$$= -iy \left[\tan\varphi \log \sin^2\varphi\right] + iy \int 2\, d\varphi$$

and the limits are $\varphi = 0$ and $\varphi = \tan^{-1}\frac{x}{y}$

$$\therefore I_x = \left[-ix \log \frac{x^2}{r^2} + 2iy \tan^{-1} \frac{x}{y}\right]$$

$$= +\left[ix \log\left(1 + \frac{y^2}{x^2}\right) + 2iy \tan^{-1} \frac{x}{y}\right]$$

Similarly,

$$I_y = -\left[iy \log\left(1 + \frac{x^2}{y^2}\right) + 2ix \tan^{-1} \frac{y}{x}\right]$$

where $I_y$ is positive outwards from O.

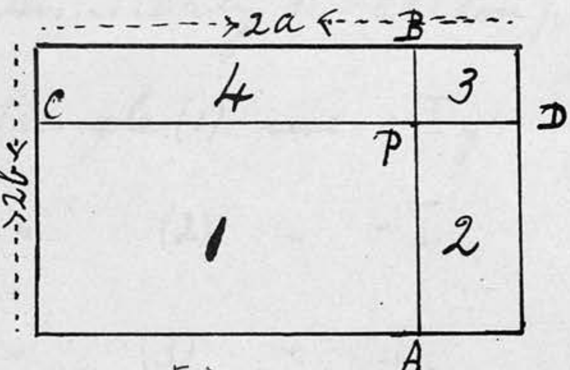



Fig. 3

To obtain the force at P due to the current in the strip find the components along PD and PB.

To get components along PD.

For rectangle (1) call PC, $x$ and PA, $y$ and use $-I_x$

For " (2) " PA, $x$ " PD, $y$ " " $I_y$

For " (3) " PD, $x$ " PB, $y$ " " $I_x$

For " (4) " PB, $x$ " PC, $y$ " " $-I_y$

Add these and we get the resultant along PD. Let us call it $F_1$

Similarly to get components along PB,

for rectangle (1) use $-I_y$

" " (2) " $-I_x$

" " (3) " $I_y$

" " (4) " $I_x$.

Add these and we get the resultant along PB. Let us call it $F_2$, and also let the resultant field at P be H.

$$\therefore H = \sqrt{F_1^2 + F_2^2}$$

We have then to evaluate $\iint H\,dx\,dy$.

This integral however is unmanageable, and I have made an approximate calculation as follows:- Suppose a quarter of the cross section of the strip to be divided up into sixteen rectangles similar to the strip. Find the values of $F_1$ and $F_2$ at the centre of each of the rectangles, and obtain the value of $H$ at these points, then finally calculate the arithmetical mean of the values of $H$. In this way I obtained an approximation from sixty four points for the whole strip.

To eliminate the residual effects of stress the wire was, in all the experiments described in this paper, demagnetised after the load had been put on. It was also placed at right angles to the earth's field.

## Iron.

A wire from the same coil as was used in the experiment in the second paper was taken. First, the modulus was determined at the temperature of the room, and was found to be the same as in that experiment, the total load being 1 Kilo. The current was next gradually increased up to the maximum, and then diminished down to zero, the same procedure being followed as in the preceding experiments. This was repeated with weights of 1.2, 1.5 and 1.8 Kilos, the results being shown in the graphs. These results are, in all cases, what was obtained after the cyclically steady state had been reached.

On examining the graphs, the first thing to be noticed is the diminution in the modulus as the weight is increased, and also the fact that the hysteresis at the same time becomes gradually smaller and smaller.

In figs. 5+6 are shown the results of those experiments in which the current was kept constant while the load was varied. An examination of them shows that as the current is increased the modulus at first increases and then diminishes We also notice that when the field is weak the effect on the modulus is small. This is seen in the graph for a field whose strength is ·7. In the next curve for field 2·6 the effect on the modulus is much more marked, and, both when the modulus is increasing and decreasing, the rate of change is greater than for the smaller field. The other curves are for increasing fields, and show the progressive change that takes place in the value of the modulus. There is a close correspondence between the results of the other method of experiment and this. In both we see that at first an increase of current is accompanied by an increase in the modulus, but that, when the current reaches a certain value, any further increase produces a diminution of the modulus. It is also to be noticed that there is a steady shift of the maximum value towards the zero of load, and that in the highest field, the value of which was 31·9, the decrease in the modulus was uniform.

# Iron.

Length = 98·34 cms.

Area of Cross-section = ·0005474 sq. cms.

Elongation Weight = 500 grams.

Total Load on Wire = 1 kilo.

Load per sq. mm. = 18·3 kilos.

## Table V.

| No. | Temp. | Elongation for 500 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 1 | 19°·4 C. | ·05072 cm. | 8 | $17·38 \times 10^{11}$ |
| 2 | 24·8 | ·04908 | 8 | 17·96 |
| 3 | 29·3 | ·04817 | 9 | 18·30 |
| 4 | 37·1 | ·04647 | 9 | 18·97 |
| 5 | 45·2 | ·04537 | 8 | 19·43 |
| 6 | 50·5 | ·04532 | 8 | 19·45 |

| No. | Temp | Elongation for 500 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 7 | 65·9 C. | ·04573 cms. | 7 | 19·28×10'' |
| 8 | 66·3 | ·04606 | 8 | 19·14 |
| 9 | 75·0 | ·04662 | 9 | 18·89 |
| 10 | 83·9 | ·04757 | 10 | 18·53 |
| 11 | 94·1 | ·04838 | 10 | 18·22 |
| 12 | 102·8 | ·04895 | 8 | 18·07 |
| 13 | 111·7 | ·04938 | 9 | 17·85 |
| 14 | 122·5 | ·04969 | 8 | 17·74 |
| 15 | 116·1 | ·04975 | 7 | 17·72 |
| 16 | 109·6 | ·04960 | 7 | 17·77 |
| 17 | 100·2 | ·04908 | 8 | 17·96 |
| 18 | 91·8 | ·04857 | 8 | 18·15 |
| 19 | 80·4 | ·04788 | 9 | 18·41 |
| 20 | 75·1 | ·04732 | 9 | 18·63 |

| No. | Temp | Elongation for 400 grams | No. of Observations | M. |
|---|---|---|---|---|
| 21 | 64°·3C. | ·04669 cm. | 8 | 18·88 x 10" |
| 22 | 55·0 | ·04676 | 10 | 18·85 |
| 23 | 50·6 | ·04709 | 9 | 18·72 |
| 24 | 46·1 | ·04747 | 9 | 18·57 |
| 25 | 38·7 | ·04836 | 7 | 18·23 |
| 26 | 29·8 | ·04958 | 8 | 17·78 |
| 27 | 23·2 | ·05046 | 8 | 17·46 |
| 28 | 19·4 | ·05072 | 9 | 17·38 |

Total load = 1·2 kilos.

= 21·9 kilos per sq. mm.

## Table VI.

| No. | Temp. | Elongation for 300 grams | No. of Observations | M. |
|---|---|---|---|---|
| 1 | 19°.5C. | ·05074 cm | 8 | $17{\cdot}37 \times 10^{11}$ |
| 2 | 22·6 | ·05009 | 8 | 17·60 |
| 3 | 28·3 | ·04916 | 9 | 17·93 |
| 4 | 34·9 | ·04799 | 9 | 18·37 |
| 5 | 40·1 | ·04739 | 10 | 18·60 |
| 6 | 45·8 | ·04732 | 10 | 18·63 |
| 7 | 52·2 | ·04741 | 8 | 18·59 |
| 8 | 61·5 | ·04786 | 9 | 18·42 |
| 9 | 69·7 | ·04807 | 7 | 18·34 |
| 10 | 78·4 | ·04847 | 7 | 18·19 |

| No. | Temp. | Elongation for 500 grams | No. of Observations | M. |
|---|---|---|---|---|
| 11 | 88°.0 C. | ·04897 cm. | 8 | 18·02×10¹¹ |
| 12 | 99·5 | ·04935 | 8 | 17·86 |
| 13 | 107·3 | ·04975 | 7 | 17·72 |
| 14 | 118·9 | ·04988 | 7 | 17·67 |
| 15 | 124·1 | ·04995 | 8 | 17·65 |
| 16 | 117·6 | ·05000 | 7 | 17·63 |
| 17 | 110·5 | ·04995 | 6 | 17·65 |
| 18 | 101·8 | ·04989 | 6 | 17·68 |
| 19 | 90·2 | ·04944 | 6 | 17·83 |
| 20 | 82·1 | ·04908 | 8 | 17·97 |
| 21 | 73·5 | ·04870 | 8 | 18·10 |
| 22 | 66·4 | ·04837 | 8 | 18·22 |
| 23 | 59·9 | ·04820 | 9 | 18·29 |
| 24 | 47·7 | ·04812 | 9 | 18·32 |

| No. | Temp. | Elongation for 500 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 25 | 43°.2 C. | ·04844 cm | 8 | 18·20×10" |
| 26 | 35·0 | ·04905 | 9 | 17·97 |
| 27 | 30·1 | ·04972 | 9 | 17·73 |
| 28 | 24·9 | ·05034 | 10 | 17·51 |
| 29 | 21·5 | ·05066 | 9 | 17·40 |
| 30 | 19·6 | ·05072 | 7 | 17·38 |

# Total load = 1·5 kilos.

= 27·4 kilos per sq. m.m.

## Table VII.

| No. | Temp. | Elongation for 5000 grams | No. of Observations | M. |
|---|---|---|---|---|
| 1 | 19°3 C. | ·05075 cm. | 7 | 17·37 x 10" |
| 2 | 25·4 | ·05011 | 7 | 17·59 |
| 3 | 30·7 | ·04958 | 9 | 17·78 |
| 4 | 36·1 | ·04938 | 8 | 17·85 |
| 5 | 48·2 | ·04944 | 9 | 17·83 |
| 6 | 57·5 | ·04952 | 8 | 17·80 |
| 7 | 69·4 | ·04961 | 8 | 17·79 |
| 8 | 81·9 | ·04972 | 6 | 17·73 |
| 9 | 90·6 | ·04980 | 6 | 17·70 |
| 10 | 103·3 | ·05003 | 8 | 17·62 |

| No. | Temp. | Elongation for 500 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 11 | 115°.7 C. | ·05014 cm. | 8 | 17·58×10¹¹ |
| 12 | 124·0 | ·05026 | 10 | 17·54 |
| 13 | 118·2 | ·05032 | 10 | 17·52 |
| 14 | 109·8 | ·05029 | 9 | 17·53 |
| 15 | 99·1 | ·05023 | 9 | 17·55 |
| 16 | 87·5 | ·05009 | 8 | 17·60 |
| 17 | 74·8 | ·04983 | 7 | 17·69 |
| 18 | 66·2 | ·04980 | 7 | 17·70 |
| 19 | 52·9 | ·04969 | 8 | 17·74 |
| 20 | 43·3 | ·04963 | 8 | 17·76 |
| 21 | 35·0 | ·04960 | 8 | 17·77 |
| 22 | 28·4 | ·05006 | 7 | 17·61 |
| 23 | 24·3 | ·05049 ~~·04937~~ | 6 | 17·46 |
| 24 | 19·3 | ·05075 | 8 | 17·37 |
| ~~25~~ | | | | |

Total load = 1·8 kilos.

= 32·9 kilos per sq. mm.

Table VIII.

| No. | Temp. | Elongation for 500 grams | No. of Observations | M. |
|---|---|---|---|---|
| 1 | 19°.5 C. | ·05078 cm. | 7 | 17·36 × 10" |
| 2 | 22·8 | ·0 5052 | 8 | 17·45 |
| 3 | 27·9 | ·05034 | 8 | 17·51 |
| 4 | 34·7 | ·05031 | 5 | 17·52 |
| 5 | 45·1 | ·05025 | 8 | 17·54 |
| 6 | 57·3 | ·05040 | 7 | 17·49 |
| 7 | 70·2 | ·05022 | 7 | 17·53 |
| 8 | 81·6 | ·05043 | 6 | 17·48 |
| 9 | 94·4 | ·05046 | 6 | 17·47 |
| 10 | 103·1 | ·05049 | 8 | 17·46 |

| No. | Temp. | Elongation for 500 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 11 | 116°.5 C. | ·05043 cm. | 8 | 17·48×10'' |
| 12 | 125·9 | ·05055 | 8 | 17·44 |
| 13 | 117·2 | ·05049 | 7 | 17·46 |
| 14 | 108·5 | ·05043 | 7 | 17·48 |
| 15 | 100·1 | ·05052 | 7 | 17·45 |
| 16 | 86·8 | ·05034 | 8 | 17·51 |
| 17 | 71·3 | ·05037 | 8 | 17·50 |
| 18 | 60·7 | ·05043 | 7 | 17·48 |
| 19 | 50·0 | ·05025 | 7 | 17·54 |
| 20 | 37·9 | ·05040 | 8 | 17·49 |
| 21 | 32·4 | ·05031 | 7 | 17·52 |
| 22 | 26·5 | ·05043 | 6 | 17·48 |
| 23 | 21·8 | ·05060 | 6 | 17·42 |
| 24 | 19·5 | ·05078 | 6 | 17·36 |

# Table IX.

| Field. | Load in kilos per sq. mm. | Elongation for 5 kilos. | No. of Observations | M. |
|---|---|---|---|---|
| ·7 | 14·6 | ·05052 cm. | 8 | 17·45 × 10¹¹ |
| | 18·3 | ·04949 | 9 | 17·81 |
| | 22·0 | ·04936 | 10 | 17·86 |
| | 27·4 | ·04972 | 9 | 17·73 |
| | 33·0 | ·05023 | 9 | 17·55 |
| | 36·5 | ·05049 | 10 | 17·46 |
| | 33·0 | ·05058 | 7 | 17·43 |
| | 27·4 | ·05020 | 8 | 17·56 |
| | 25·0 | ·05003 | 9 | 17·62 |
| | 22·0 | ·04991 | 9 | 17·66 |
| | 18·3 | ·05003 | 8 | 17·62 |
| | 14·6 | ·05052 | 7 | 17·45 |

# Table X.

| Field. | Load in Kilos per sq: mm | Elongation for ·5 Kilos. | No. of Observations | M. |
|---|---|---|---|---|
| 2·6 | 14·6 | ·04983 cm. | 8 | 17·69×10¹¹ |
| | 18·3 | ·04707 | 9 | 18·73 |
| | 22·0 | ·04679 | 7 | 18·84 |
| | 27·4 | ·04801 | 8 | 18·36 |
| | 33·0 | ·04942 | 9 | 17·80 |
| | 36·5 | ·05000 | 9 | 17·63 |
| | 33·0 | ·04986 | 7 | 17·68 |
| | 27·4 | ·04865 | 7 | 18·12 |
| | 22·0 | ·04757 | 6 | 18·53 |
| | 18·3 | ·04801 | 8 | 18·36 |
| | 14·6 | ·04983 | 8 | 17·69 |

# Table XI.

| Field. | Load in Kilos per sq. mm. | Elongation for ·5 Kilos. | No. of Observations | M. |
|---|---|---|---|---|
| 5·5 | 14·6 | ·04788 cm. | 8 | 18·41 × 10¹¹ |
| | 18·3 | ·04539 | 9 | 19·42 |
| | 22·0 | ·04570 | 9 | 19·29 |
| | 27·4 | ·04832 | 10 | 18·67 |
| | 33·0 | ·04899 | 7 | 17·96 |
| | 36·5 | ·04991 | 7 | 17·66 |
| | 33·0 | ·04938 | 8 | 17·85 |
| | 27·4 | ·04783 | 10 | 18·43 |
| | 22·0 | ·04642 | 8 | 18·95 |
| | 18·3 | ·04648 | 8 | 18·93 |
| | 14·6 | ·04788 | 9 | 18·41 |

# Table XII.

| Field | Load in Kilos per sq. mm. | Elongation for ·5 Kilos. | No. of Observations | M. |
|---|---|---|---|---|
| 9·1 | 14·6 | ·04577 cm. | 8 | 19·26 x 10'' |
| | 18·3 | ·04425 | 7 | 19·92 |
| | 22·0 | ·04477 | 8 | 19·70 |
| | 27·4 | ·04637 | 5 | 19·01 |
| | 33·0 | ·04838 | 6 | 18·22 |
| | 36·5 | ·04953 | 6 | 17·79 |
| | 33·0 | ·04884 | 7 | 18·05 |
| | 27·4 | ·04694 | 7 | 18·78 |
| | 22·0 | ·04546 | 9 | 19·39 |
| | 18·3 | ·04487 | 8 | 19·65 |
| | 14·6 | ·04577 | 8 | 19·26 |

# Table XIII.

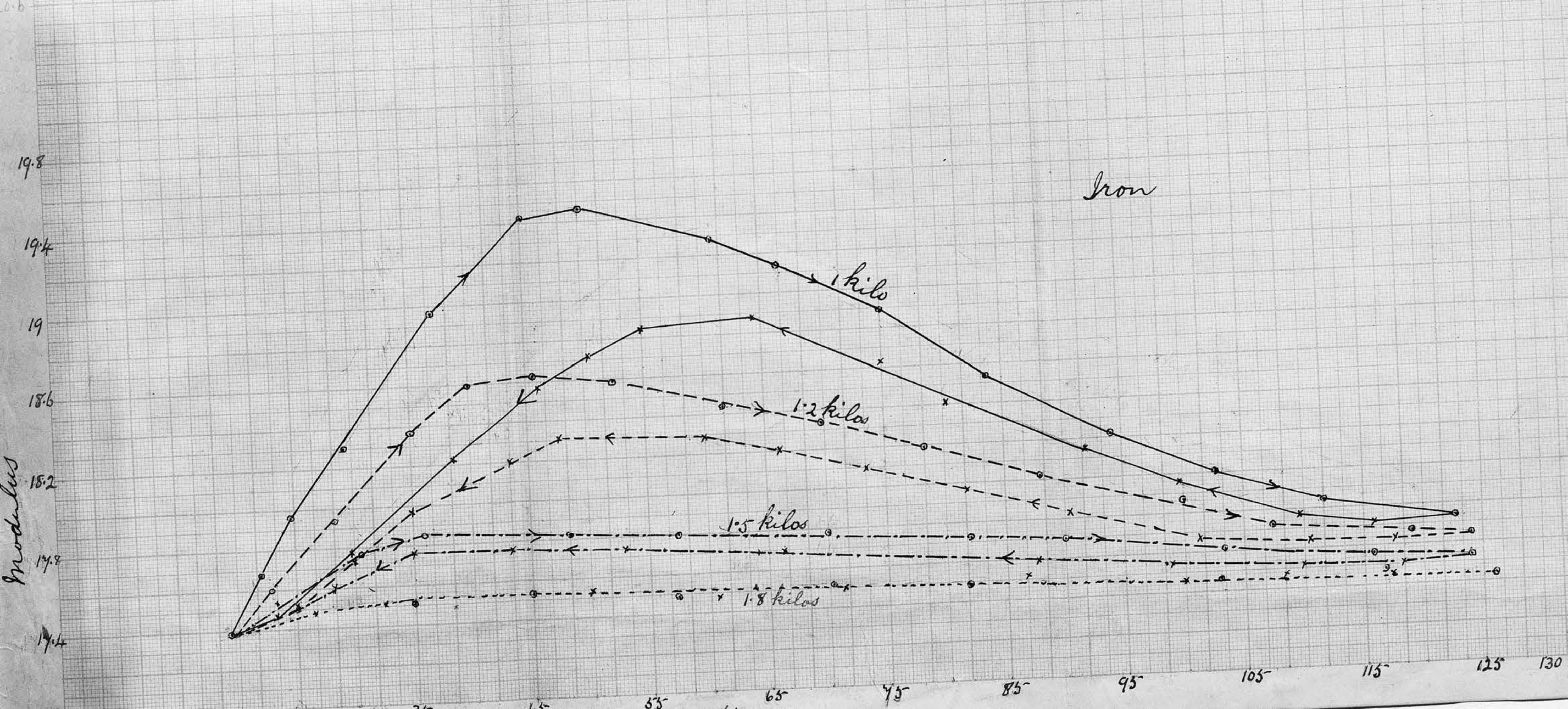
| Field | Load in Kilos per sq. mm. | Elongation for ·5 Kilo. | No. of Observations | M. |
|---|---|---|---|---|
| 15·3 | 14·6 | ·04608 cm. | 8 | 19·13×10" |
| | 18·3 | ·04535 | 7 | 19·44 |
| | 22·0 | ·04587 | 8 | 19·22 |
| | 27·4 | ·04729 | 7 | 18·64 |
| | 33·0 | ·04895 | 7 | 18·01 |
| | 36·5 | ·04947 | 9 | 17·82 |
| | 33·0 | ·04914 | 9 | 17·94 |
| | 27·6 | ·04801 | 8 | 18·36 |
| | 22·0 | ·04666 | 8 | 18·89 |
| | 18·3 | ·04599 | 6 | 19·17 |
| | 14·6 | ·04608 | 6 | 19·13 |

# Table XIV.

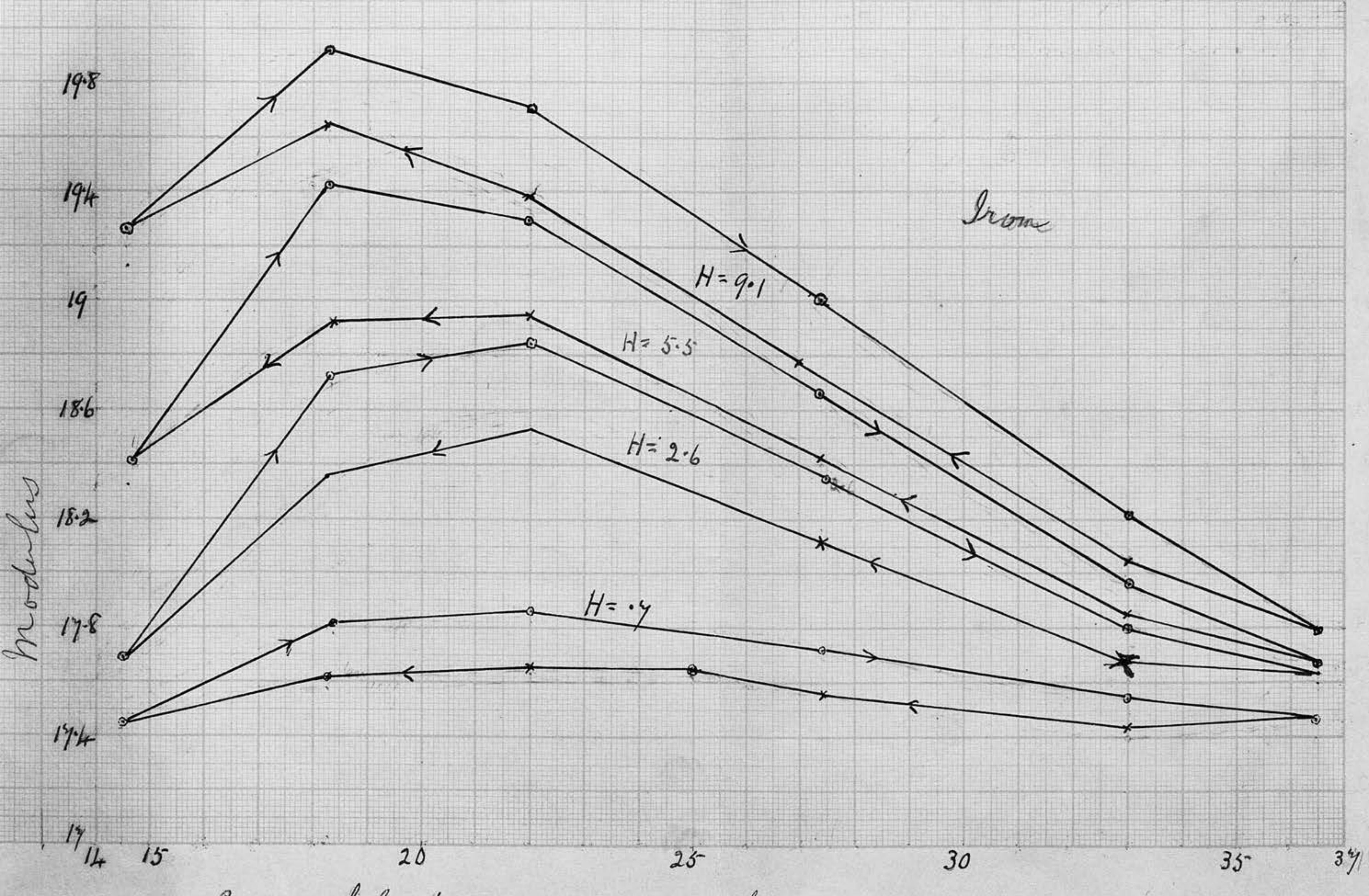
| Field. | Load in Kilos per sq. mm. | Elongation for ·5 Kilo. | No. of Observations | M. |
|---|---|---|---|---|
| 20·6 | 14·6 | ·04770 cm. | 9 | 18·48 × 10[11] |
| | 16·5 | ·04742 | 7 | 18·59 |
| | 18·3 | ·04757 | 6 | 18·53 |
| | 22·0 | ·04823 | 6 | 18·28 |
| | 27·4 | ·04911 | 8 | 17·95 |
| | 33·0 | ·04975 | 8 | 17·72 |
| | 36·5 | ·05000 | 7 | 17·63 |
| | 33·0 | ·04994 | 7 | 17·65 |
| | 27·4 | ·04932 | 8 | 17·87 |
| | 22·0 | ·04838 | 6 | 18·22 |
| | 18·3 | ·04770 | 6 | 18·48 |
| | 16·5 | ·04752 | 8 | 18·55 |
| | 14·6 | ·04770 | 5 | 18·48 |

# Table XV.

| Field. | Load in kilos per sq. mm. | Elongation for ·5 kilo. | No. of Observations | M. |
|---|---|---|---|---|
| 31·9 | 14·6 | ·05009 cm. | 8 | 17·60 × 10" |
| | 18·3 | ·05014 | 9 | 17·58 |
| | 22·0 | ·05029 | 5 | 17·53 |
| | 27·4 | ·05032 | 6 | 17·52 |
| | 33·0 | ·05037 | 6 | 17·50 |
| | 36·5 | ·05040 | 8 | 17·49 |
| | 33·0 | ·05040 | 9 | 17·49 |
| | 27·4 | ·05026 | 8 | 17·54 |
| | 22·0 | ·05026 | 8 | 17·54 |
| | 18·3 | ·05020 | 10 | 17·56 |
| | 14·6 | ·05006 | 8 | 17·61 |

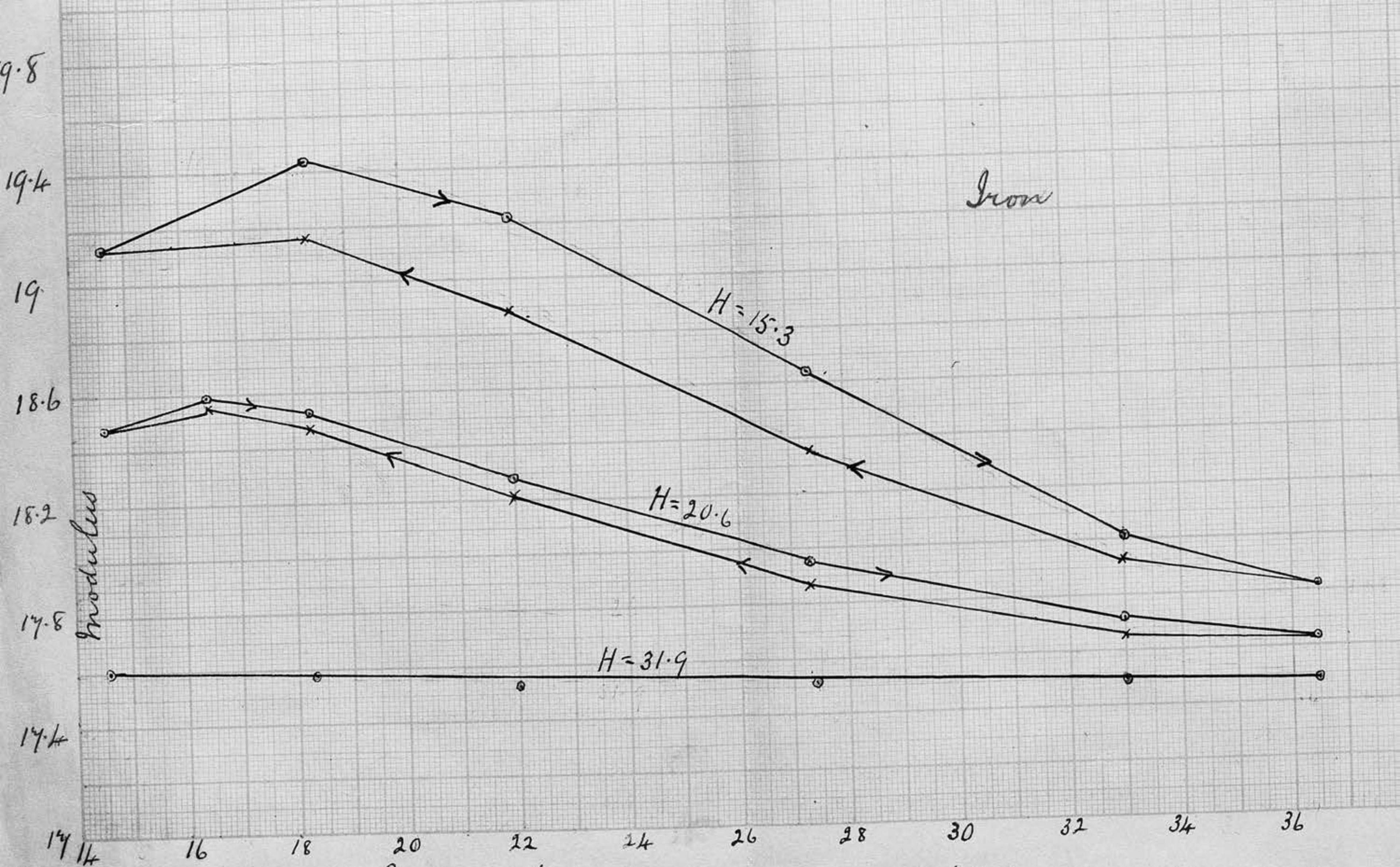


Iron
1 kilo
1·2 kilos
1·5 kilos
1·8 kilos
Modulus
19.8
19·4
19
18.6
18.2
17.8
17.4
55
65
75
85
95
105
115
125
130



Iron
H = 9·1
H = 5·5
H = 2·6
H = ·4
19·8
19·4
19
18·6
18·2
17·8
17·4
17
14
15
20
25
30
35
37
Modulus
Load in kilos per sq. mm.


fig. 5


Iron
H = 15·3
H = 20·6
H = 31·9
Modulus
19·8
19·4
19
18·6
18·2
17·8
17·4
17
14
16
18
20
22
24
26
28
30
32
34
36
Load in kilos per sq. mm.
fig. 6

# Steel.

A wire of the same gauge as in the preceding experiments was used, and was put through successive cycles of heating and cooling, the loads being 1·1, 1·4, 1·7, and 2 kilos. The resulting curves are shown in fig 7, each one being that obtained after the cyclic state had been reached. It will be seen that the modulus diminishes as the weight is increased, that is, at the same stage in any two cycles in that cycle in which the load is smaller the modulus has a greater value.

Speaking generally, we are able to say from a comparison of the curves obtained under similar conditions, - e.g. figs 4 and 7, 5 and 8, 6 and 9, — that the effects of an electric current on Young's Modulus is the same in steel as in iron. At the same time there are certain differences, for it will be seen that, when the current is diminishing, the curves at first lie above those at the same temperature for increasing current. Again, as the load is increased, the value of the modulus falls, and the maximum value is also reached in a weaker field, a result similar to what was found for iron.

An examination of the curves when the current was kept constant, and the load varied, shows that the curve for unloading is at first higher than that for loading, a point in which steel differs from iron. It is also seen that increase of field produces at first increase in the modulus, but that when it rises above a certain value, a further increase causes the modulus to diminish. In the highest field there is a uniform decrease, and the curve becomes a straight line.

# Steel.

Length = 98·42 cms.

Area of Cross-section = ·0004714 sq. cms.

Elongation Weight = 500 grams.

Total Load on Wire = 1·1 kilo.

Load per sq. mm. = 23·3 kilos per sq mm.

## Table V.

| No. | Temp. | Elongation for 500 grams | No. of Observations | M. |
|---|---|---|---|---|
| 1 | 14°8C. | ·04835 cm. | 8 | 21·19×10" |
| 2 | 20·2 | ·04812 | 9 | 21·29 |
| 3 | 26·3 | ·04792 | 9 | 21·38 |
| 4 | 30·0 | ·04781 | 10 | 21·43 |
| 5 | 33·4 | ·04776 | 8 | 21·45 |
| 6 | 36·9 | ·04776 | 8 | 21·45 |

| No. | Temp | Elongation for 500 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 7 | 44°·1 C. | ·04779 cm. | 8 | 21·44 × 10[11] |
| 8 | 51·7 | ·04788 | 7 | 21·40 |
| 9 | 60·6 | ·04794 | 7 | 21·37 |
| 10 | 68·3 | ·04806 | 9 | 21·32 |
| 11 | 77·8 | ·04825 | 9 | 21·25 |
| 12 | 87·5 | ·04828 | 8 | 21·22 |
| 13 | 98·0 | ·04838 | 8 | 21·18 |
| 14 | 105·7 | ·04844 | 7 | 21·15 |
| 15 | 115·4 | ·04846 | 7 | 21·14 |
| 16 | 109·2 | ·04840 | 9 | 21·17 |
| 17 | 101·9 | ·04824 | 9 | 21·24 |
| 18 | 94·3 | ·04806 | 8 | 21·32 |
| 19 | 85·7 | ·04779 | 8 | 21·44 |
| 20 | 72·8 | ·04750 | 8 | 21·57 |

| No. | Temp. | Elongation for 300 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 21. | 68°.1 C. | ·04745 cm. | 8 | 21·59×10¹¹ |
| 22. | 61·5 | ·04743 | 7 | 21·60 |
| 23. | 53·6 | ·04745 | 7 | 21·59 |
| 24. | 45·2 | ·04759 | 8 | 21·53 |
| 25. | 40·0 | ·04770 | 6 | 21·48 |
| 26. | 34·7 | ·04788 | 6 | 21·40 |
| 27. | 29·8 | ·04804 | 6 | 21·33 |
| 28. | 22·3 | ·04821 | 8 | 21·25 |
| 29. | 18·4 | ·04828 | 7 | 21·22 |
| 30. | 14·8 | ·04835 | 7 | 21·19 |

Total load = 1·4 kilo.

= ~~29.1~~ 29·7 kilos per sq. mm.

# Table VI.

| No. | Temp. | Elongation for 500 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 1. | 14°·7 C. | ·04835 cm. | 7 | 21·19 × 10'' |
| 2. | 19·5 | ·04823 | 7 | 21·26 |
| 3. | 24·6 | ·04808 | 8 | 21·31 |
| 4. | 30·1 | ·04799 | 6 | 21·35 |
| 5. | 35·8 | ·04797 | 6 | 21·36 |
| 6. | 41·4 | ·04799 | 8 | 21·35 |
| 7. | 49·9 | ·04804 | 8 | 21·33 |
| 8. | 57·7 | ·04815 | 7 | 21·28 |
| 9. | 68·3 | ·04823 | 7 | 21·24 |
| 10. | 78·0 | ·04833 | 7 | 21·20 |

| No. | Temp. | Elongation for 300 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 11. | 86°.6 C. | ·04840 cm. | 7 | 21·17x10" |
| 12. | 98·5 | ·04849 | 7 | 21·13 |
| 13. | 107·4 | ·04856 | 8 | 21·11 |
| 14. | 116·0 | ·04858 | 8 | 21·10 |
| 15. | 110·1 | ·04854 | 7 | 21·12 |
| 16. | 103·8 | ·04844 | 7 | 21·15 |
| 17. | 94·2 | ·04831 | 9 | 21·21 |
| 18. | 82·5 | ·04813 | 9 | 21·29 |
| 19. | 70·7 | ·04797 | 8 | 21·36 |
| 20. | 61·3 | ·04781 | 7 | 21·43 |
| 21. | 55·9 | ·04776 | 7 | 21·45 |
| 22. | 46·7 | ·04776 | 8 | 21·45 |
| 23. | 41·2 | ·04786 | 8 | 21·41 |
| 24. | 36·4 | ·04802 | 9 | 21·34 |

| No. | Temp. | Elongation for 800 grams | No. of Observations | M. |
|---|---|---|---|---|
| 25. | 31°.1 C. | ·04813 cm. | 8. | 21·29×10'' |
| 26. | 25·6 | ·04819 | 9 | 21·26 |
| 27. | 20·5 | ·04826 | 9 | 21·23 |
| 28. | 17·8 | ·04831 | 7 | 21·21 |
| 29. | 14·7 | ·04835 | 6 | 21·19 |

# Total load = 1·7 kilo

= 36·0 kilos per sq. mm.

## Table VII.

| No. | Temp. | Elongation pr 500 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 1. | 15°·0 C. | ·04838 C. | 8 | 21·18×10" |
| 2. | 20·3 | ·04825 | 7 | 21·23 |
| 3. | 25·9 | ·04817 | 7 | 21·27 |
| 4. | 31·4 | ·04815 | 6 | 21·28 |
| 5. | 40·8 | ·04819 | 6 | 21·26 |
| 6. | 48·7 | ·04819 | 5 | 21·26 |
| 7. | 57·6 | ·04828 | 5 | 21·22 |
| 8. | 69·5 | ·04840 | 8 | 21·17 |
| 9. | 80·1 | ·04849 | 9 | 21·13 ~~21·08~~ |
| 10. | 89·3 | ·04861 | 9 | 21·08 ~~21·05~~ |

| No. | Temp. | Elongation for 300 grams | No. of Observations | M. |
|---|---|---|---|---|
| 11 | 99°·8 C. | ·04867 cm. | 9 | $21{\cdot}03\times10^{11}$ |
| 12 | 111·6 | ·04878 | 9 | 21·01 |
| 13 | 115·9 | ·04880 | 8 | 21·00 |
| 14 | 109·5 | ·04872 | 8 | 21·03 |
| 15 | 102·7 | ·04865 | 10 | 21·06 |
| 16 | 93·2 | ·04856 | 10 | 21·11 |
| 17 | 81·8 | ·04842 | 8 | 21·16 |
| 18 | 70·0 | ·04828 | 8 | 21·22 |
| 19 | 62·5 | ·04821 | 7 | 21·25 |
| 20 | 55·1 | ·04813 | 7 | 21·29 |
| 21 | 50·2 | ·04808 | 8 | 21·31 |
| 22 | 43·4 | ·04810 | 8 | 21·30 |
| 23 | 35·7 | ·04815 | 7 | 21·~~38~~ 28 |
| ~~24~~ | | | | |

| No. | Temp. | Elongation for 500 grams | No. of Observations | M. |
|---|---|---|---|---|
| 24 | 28°.6 C | ·04819 cm. | 7 | 21·26x10'' |
| 25 | 23·3 | ·04826 | 7 | 21·23 |
| 26 | 18·8 | ·04835 | 9 | 21·19 |
| 27 | 15·1 | ·04838 | 9 | 21·18 |

Total load = 2 kilos.

= 42·4 kilos. per sq. mm.

## Table VIII.

| No. | Temp. | Elongation for 500 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 1 | 15°·1 C. | ·04838 cm. | 7 | 21·18x10" |
| 2 | 19·8 | ·04835 | 4 | 21·19 |
| 3 | 25·6 | ·04828 | 8 | 21·22 |
| 4 | 30·7 | ·04828 | 8 | 21·22 |
| 5 | 36·2 | ·04831 | 6 | 21·21 |
| 6 | 44·5 | ·04835 | 6 | 21·19 |
| 7 | 55·7 | ·04844 | 8 | 21·15 |
| 8 | 67·3 | ·04856 | 8 | 21·11 |
| 9 | 76·9 | ·04865 | 9 | 21·06 |
| 10 | 89·2 | ·04875 | 9 | 21·02 |

| No. | Temp. | Elongation for 500 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 11 | 100°·1 C. | ·04883 cm. | 8 | 20·98 x 10" |
| 12 | 111·8 | ·04895 | 9 | 20·93 |
| 13 | 117·0 | ·04895 | 9 | 20·93 |
| 14 | 109·1 | ·04888 | 8 | 20·96 |
| 15 | 100·7 | ·04882 | 7 | 20·99 |
| 16 | 88·6 | ·04867 | 7 | 21·05 |
| 17 | 75·4 | ·04861 | 8 | 21·08 |
| 18 | 63·3 | ·04847 | 7 | 21·14 |
| 19 | 54·2 | ·04838 | 7 | 21·18 |
| 20 | 44·4 | ·04828 | 9 | 21·22 |
| 21 | 35·1 | ·04823 | 8 | 21·24 |
| 22 | 31·3 | ·04823 | 6 | 21·24 |
| 23 | 26·8 | ·04831 | 7 | 21·21 |
| 24 | 20·5 | ·04835 | 7 | 21·19 |
| 25 | 17·9 | ·04835 | 5 | 21·19 |
| 26 | 15·1 | ·04838 | 8 | 21·18 |

# Table IX.

| Field | Load in Kilos per sq. mm | Elongation for ·5 kilo | No. of Observations | M. |
|---|---|---|---|---|
| ·65 | 16·9 | ·04830 cm | 8 | 21·21 × 10" |
| | 23·3 | ·04812 | 9 | 21·29 |
| | 29·7 | ·04808 | 9 | 21·31 |
| | 36·0 | ·04817 | 8 | 21·27 |
| | 42·4 | ·04826 | 6 | 21·23 |
| | 46·7 | ·04833 | 6 | 21·20 |
| | 42·4 | ·04820 | 8 | 21·26 |
| | 36·0 | ·04808 | 7 | 21·31 |
| | 29·7 | ·04806 | 7 | 21·32 |
| | 23·3 | ·04817 | 6 | 21·27 |
| | 16·9 | ·04830 | 8 | 21·21 |

# Table X.

| Field | Load in kilos per sq. mm. | Elongation for ·5 kilo. | No. of Observations | M. |
|---|---|---|---|---|
| 3·7 | 16·9 | ·04812 cm. | 8 | 21·29 |
| | 23·3 | ·04774 | 6 | 21·46 |
| | 29·7 | ·04765 | 6 | 21·50 |
| | 36·0 | ·04783 | 7 | 21·42 |
| | 42·4 | ·04808 | 7 | 21·31 |
| | 46·7 | ·04824 | 9 | 21·24 |
| | 42·4 | ·04792 | 8 | 21·38 |
| | 36·0 | ·04759 | 7 | 21·53 |
| | 29·7 | ·04752 | 6 | 21·56 |
| | 23·3 | ·04785 | 6 | 21·41 |
| | 16·9 | ·04812 | 6 | 21·29 |

# Table XI.

| Field. | Load in kilos per sq. mm. | Elongation for ·5 kilo. | No. of Observations. | M. |
|---|---|---|---|---|
| 8·5 | 16·9 | ·04794 cm. | 8 | 21·37×10" |
| | 23·3 | ·04743 | 6 | 21·60 |
| | 29·7 | ·04741 | 7 | 21·61 |
| | 36·0 | ·04767 | 7 | 21·49 |
| | 42·4 | ·04801 | 7 | 21·34 |
| | 46·7 | ·04825 | 9 | 21·25 |
| | 42·4 | ·04776 | 8 | 21·45 |
| | 36·0 | ·04739 | 8 | 21·62 |
| | 29·7 | ·04730 | 7 | 21·66 |
| | 23·3 | ·04745 | 7 | 21·59 |
| | 16·9 | ·04794 | 5 | 21·37 |

# Table XII.

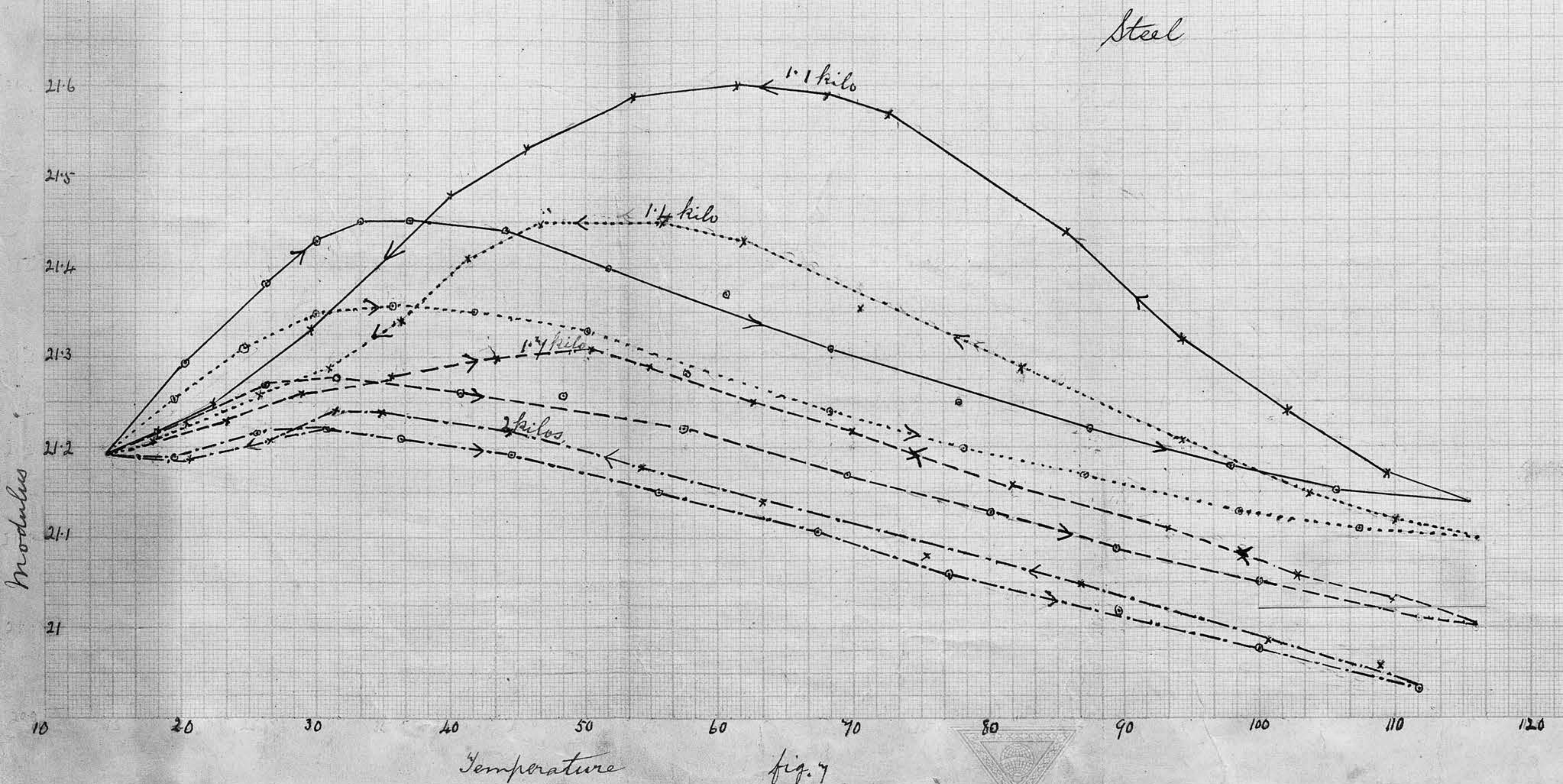
| Field | Load in kilos per sq. mm. | Elongation for ·5 Kilo. | No. of Observations | M. |
|---|---|---|---|---|
| 17·4 | 16·9 | ·04801 cm. | 7 | 21·34 x 10^11 |
| | 20·0 | ·04774 | 8 | 21·46 |
| | 23·3 | ·04767 | 5 | 21·49 |
| | 29·7 | ·04783 | 8 | 21·62 |
| | 36·0 | ·04812 | 8 | 21·29 |
| | 42·4 | ·04842 | 6 | 21·16 |
| | 46·7 | ·04853 | 7 | 21·11 |
| | 42·4 | ·04826 | 8 | 21·23 |
| | 36·0 | ·04785 | 9 | 21·41 |
| | 29·7 | ·04761 | 9 | 21·52 |
| | 23·3 | ·04767 | 8 | 21·49 |
| | 20·0 | ·04783 | 10 | 21·42 |
| | 16·9 | ·04801 | 10 | 21·34 |

# Table XIII.

| Field | Load in Kilos per sq. mm | Elongation for ·5 Kilo. | No. of Observations | M |
|---|---|---|---|---|
| 28·5 | 16·9 | ·04815 cm. | 7 | 21·28 × 10" |
| | 20·0 | ·04808 | 8 | 21·31 |
| | 23·3 | ·04810 | 9 | 21·30 |
| | 29·7 | ·04828 | 8 | 21·22 |
| | 36·0 | ·04847 | 10 | 21·14 |
| | 42·4 | ·04863 | 9 | 21·07 |
| | 46·7 | ·04870 | 9 | 21·04 |
| | 42·4 | ·04855 | 8 | 21·10 |
| | 36·0 | ·04835 | 7 | 21·19 |
| | 29·7 | ·04810 | 7 | 21·30 |
| | 23·3 | ·04807 | 8 | 21·34 |
| | 20·0 | ·04810 | 8 | 21·30 |
| | 16·9 | ·04815 | 6 | 21·28 |

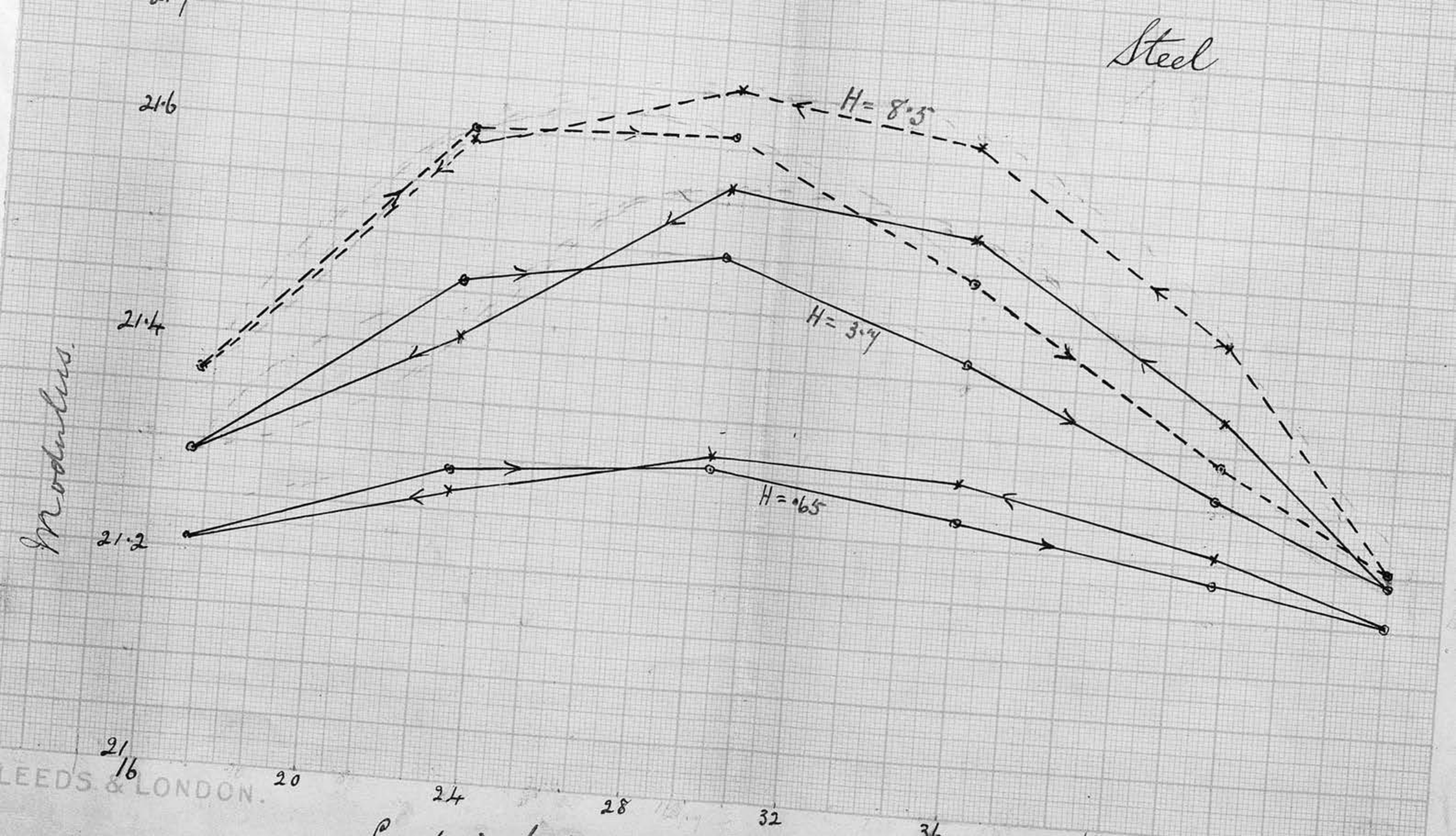
# Table XIV.

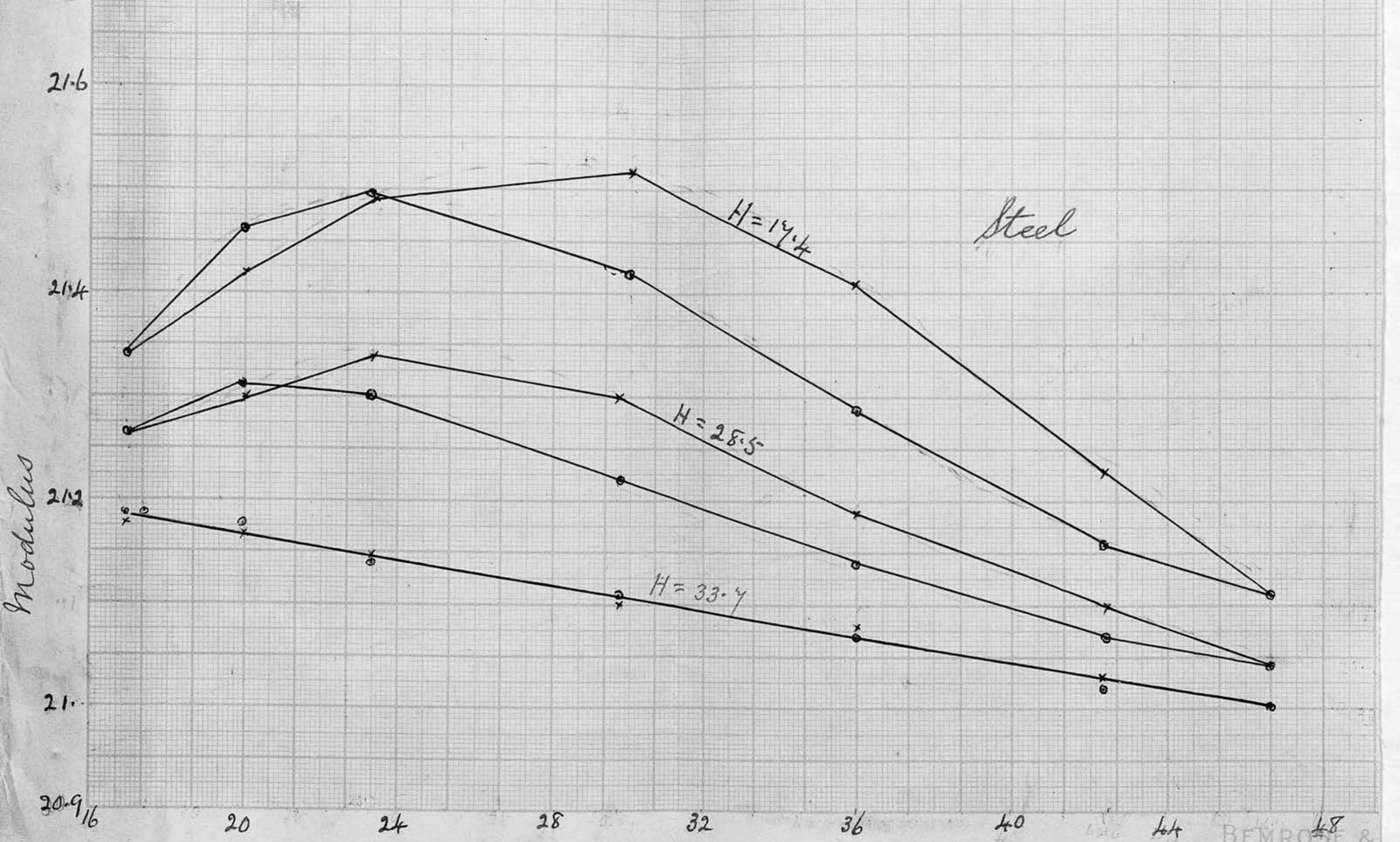
| Field. | Load in kilos per sq. mm. | Elongation for ·5 Kilo. | No. of Observations | M. |
|---|---|---|---|---|
| 33·7 | 16·9 | ·04835 cm. | 8 | $21{\cdot}19 \times 10^{11}$ |
| | 20·0 | ·04837 | 8 | 21·18 |
| | 23·3 | ·04847 | 8 | 21·14 |
| | 29·7 | ·04853 | 10 | 21·11 |
| | 36·0 | ·04863 | 10 | 21·07 |
| | 42·4 | ·04874 | 8 | 21·02 |
| | 46·7 | ·04879 | 8 | 21·00 |
| | 42·4 | ·04872 | 9 | 21·03 |
| | 36·0 | ·04861 | 8 | 21·08 |
| | 29·7 | ·04855 | 9 | 21·10 |
| | 23·3 | ·04844 | 9 | 21·15 |
| | 20·0 | ·04840 | 6 | 21·17 |
| | 16·9 | ·04837 | 6 | 21·18 |



Steel
1·1 kilo
1·4 kilo
1·7 kilo
2 kilos
21·6
21·5
21·4
21·3
21·2
21·1
21
10
20
30
40
50
60
70
80
90
100
110
120
Modulus
Temperature

fig. 7


Steel
21·6
21·4
21·2
21
Modulus
H = 8·5
H = 3·4
H = ·65
16
20
24
28
32
LEEDS & LONDON.



Load in kilos per sq. mm.

fig. 9

# Nickel.

As already stated in the introductory part of this Paper, nickel was subjected to experiment in the same way as iron and steel. The wire was first stretched for 24 hours with the greatest load that was to be put on it, and then the modulus determined at the temperature of the room before any current was passed. The wire was demagnetised by reversals to eliminate the residual effects of the stress, the current increased step by step until the temperature was above 150° C., and at each step the modulus was determined. It will be seen that the modulus with the current was higher than the value before any current was passed through the wire; and also that the value when the load was 1·5 Kilo. was greater, after the cyclic state had been reached, than during the first cycle. The other curves give the results that were obtained after the cyclic state had in each case been reached.

Before commencing each of the other cycles the wire was demagnetised and the loads were 2·2, 2·9, 3·5, and 4 Kilos. It will be seen from fig. 11 that as the weight is increased the modulus falls in value, that the hysteresis diminishes with increase of load, and that with the greatest load the modulus diminishes uniformly, the curve being a straight line.

At the conclusion of these cycles the wire was again demagnetised, and the modulus determined at the temperature of the room without any current. It was found to be higher than the first determination, so that the current had produced a permanent increase in the modulus.

Another piece of wire from the same coil was next passed through the double-walled tube, and the modulus determined for ordinary heating at the same temperatures as before by this method of heating, — viz: that of the air, 35°, 78°, 100°, and 130°. As was to be expected, the graph was a straight line, showing that the modulus diminishes uniformly when the wire is heated in this manner

Finally, as stated in the general outline of the course at the begining of this Paper, the current was kept constant while the load was varied. The curves are shown in figs. 12 and 13, and it is at once evident that they are very similar to those for iron.

In order to eliminate any effect of torsion which might be produced by the wire hanging over the pulley, I attached the scale pan to the wire by a string which was passed over the wheel.

On looking at the curves of fig. 11 we see that the effect of the current is first to produce an increase in the modulus, a maximum is reached, after which it begins to diminish. Next, as the load is increased the value of the modulus diminishes until, with the greatest load used, the decrease is uniform. It will also be seen that as the load increases the maximum value is reached in weaker fields, and that the curve for diminishing current always lies below the one for increasing current.

# Nickel.

Length = 97·82 cms.

Area of Cross-section = ·001195 sq. cms.

Elongation Weight = 700 grams.

Total Load on wire = 1·5 kilos.

Load per sq. mm. = 12·5 kilos.

## Table I. – First Cycle.

| No. | Temp. | Elongation for 700 grams | No. of Observations | M. |
|---|---|---|---|---|
| 1. | 16°·0 C. | ·04022 cm. | 8 | $13·98 \times 10^{11}$ |
| 2. | 22·3 | ·03969 | 9 | 14·17 |
| 3. | 28·6 | ·03878 | 9 | 14·50 |
| 4. | 33·7 | ·03830 | 8 | 14·68 |
| 5. | 40·1 | ·03799 | 10 | 14·80 |
| 6. | 48·4 | ·03776 | 8 | 14·89 |

| No. | Temp. | Elongation for 400 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 7. | 53°·2 C. | ·03771 | 9 | 14·91 × 10″ |
| 8. | 59·8 | ·03774 | 9 | 14·90 |
| 9. | 68·5 | ·03792 | 8 | 14·83 |
| 10. | 79·1 | ·03838 | 8 | 14·65 |
| 11. | 92·9 | ·03916 | 10 | 14·36 |
| 12. | 103·6 | ·03965 | 9 | 14·15 |
| 13. | 117·4 | ·04071 | 8 | 14·02 |
| 14. | 130·7 | ·04086 | 7 | 13·76 |
| 15. | 139·0 | ·04113 | 7 | 13·67 |
| 16. | 152·6 | ·04150 | 6 | 13·55 |
| 17. | 143·5 | ·04147 | 6 | 13·56 |
| 18. | 132·7 | ·04125 | 6 | 13·63 |
| 19. | 125·4 | ·04110 | 6 | 13·68 |
| 20. | 114·3 | ·04068 | 6 | 13·82 |

| No. | Temp. | Elongation for 700grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 21. | 102°·9C. | ·04039cm. | 8 | 13·92 x 10'' |
| 22. | 94·6 | ·04005 | 6 | 14·04 |
| 23. | 83·0 | ·03966 | 6 | 14·18 |
| 24. | 75·8 | ·03921 | 9 | 14·34 |
| 25. | 61·3 | ·03882 | 9 | 14·49 |
| 26. | 52·7 | ·03884 | 8 | 14·48 |
| 27. | 44·2 | ·03897 | 5 | 14·43 |
| 28. | 38·1 | ·03930 | 5 | 14·32 |
| 29. | 29·6 | ·03963 | 7 | 14·19 |
| 30. | 23·5 | ·04000 | 6 | 14·06 |
| 31. | 16·2 | ·04048 | 9 | 13·89 |

# Table II. – Final Cycle for 1·5 kilo.

| No. | Temp. | Elongation for 700 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 1. | 10°·6 C. | ·04178 cm. | 7 | $13{\cdot}46 \times 10^{11}$ |
| 2. | 16·7 | ·04014 | 7 | 14·01 |
| 3. | 23·6 | ·03900 | 9 | 14·42 |
| 4. | 30·1 | ·03817 | 9 | 14·73 |
| 5. | 38·3 | ·03779 | 8 | 14·88 |
| 6. | 46·9 | ·03749 | 6 | 15·00 |
| 7. | 51·2 | ·03741 | 6 | 15·03 |
| 8. | 59·5 | ·03739 | 5 | 15·04 |
| 9. | 65·8 | ·03750 | 7 | 14·99 |
| 10. | 78·4 | ·03801 | 7 | 14·79 |
| 11. | 89·6 | ·03873 | 7 | 14·52 |
| 12. | 101·0 | ·03952 | 8 | 14·23 |

| No. | Temp | Elongation for 100 grams | No. of Observations | M. |
|---|---|---|---|---|
| 13. | 120°3 C. | ·04039 cm. | 8 | $13{\cdot}92 \times 10^{11}$ |
| 14. | 136·7 | ·04098 | 9 | 13·72 |
| 15. | 153·8 | ·04144 | 8 | 13·57 |
| 16. | 142·5 | ·04141 | 7 | 13·58 |
| 17. | 129·6 | ·04107 | 7 | 13·69 |
| 18. | 114·2 | ·04069 | 8 | 13·82 |
| 19. | 97·1 | ·03996 | 5 | 14·07 |
| 20. | 80·3 | ·03919 | 6 | 14·35 |
| 21. | 68·5 | ·03870 | 6 | 14·53 |
| 22. | 60·4 | ·03857 | 7 | 14·58 |
| 23. | 53·1 | ·03851 | 8 | 14·60 |
| 24. | 41·9 | ·03875 | 8 | 14·51 |
| 25. | 33·0 | ·03911 | 6 | 14·38 |
| 26. | 27·1 | ·03935 | 7 | 14·29 |
| 27. | 22·6 | ·03969 | 8 | 14·17 |
| 28. | 16·8 | ·04010 | 8 | 14·02 |

Total load = 2·2 kilos.

= 18·4 kilos per sq. mm.

Table III.

| No. | Temp. | Elongation for 700 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 1 | 17°·0 C. | ·04018 cm | 8 | $13·99 \times 10^{11}$ |
| 2 | 24·1 | ·03941 | 7 | 14·27 |
| 3 | 29·4 | ·03900 | 8 | 14·42 |
| 4 | 38·6 | ·03851 | 7 | 14·60 |
| 5 | 43·5 | ·03838 | 7 | 14·65 |
| 6 | 50·2 | ·03836 | 9 | 14·66 |
| 7 | 59·7 | ·03857 | 9 | 14·58 |
| 8 | 71·9 | ·03938 | 8 | 14·28 |
| 9 | 85·4 | ·04000 | 8 | 14·06 |
| 10 | 98·7 | ·04059 | 9 | 13·85 |

| No. | Temp. | Elongation for 400 grams | No. of Observations | M |
|---|---|---|---|---|
| 11. | 114°·5 C. | ·04110 cm. | 10 | 13·68×10¹¹ |
| 12. | 129·1 | ·04162 | 8 | 13·51 |
| 13. | 145·8 | ·04203 | 7 | 13·38 |
| 14. | 158·7 | ·04212 | 7 | 13·35 |
| 15. | 146·0 | ·04206 | 7 | 13·37 |
| 16. | 132·3 | ·04187 | 6 | 13·43 |
| 17. | 117·2 | ·04141 | 8 | 13·58 |
| 18. | 101·5 | ·04092 | 8 | 13·74 |
| 19. | 82·6 | ·04028 | 7 | 13·96 |
| 20. | 67·4 | ·03954 | 7 | 14·22 |
| 21. | 53·9 | ·03908 | 6 | 14·39 |
| 22. | 45·8 | ·03902 | 6 | 14·41 |
| 23. | 36·3 | ·03913 | 6 | 14·37 |
| 24. | 28·2 | ·03944 | 7 | 14·26 |
| 25. | 21·0 | ·03994 | 8 | 14·08 |
| 26. | 17·0 | ·04018 | 8 | 13·99 |

Total load = 2·9 kilos.

= 24·3 kilos per sq. mm.

## Table IV.

| No. | Temp. | Elongation for 100 grams | No. of Observations | M. |
|---|---|---|---|---|
| 1. | 17°·9 C. | ·04021 cm. | 7 | $13·98 \times 10^{11}$ |
| 2. | 23·4 | ·03966 | 8 | 14·18 |
| 3. | 30·7 | ·03927 | 9 | 14·32 |
| 4. | 36·8 | ·03921 | 9 | 14·34 |
| 5. | 42·1 | ·03932 | 6 | 14·30 |
| 6. | 51·2 | ·03966 | 6 | 14·18 |
| 7. | 59·4 | ·03992 | 8 | 14·09 |
| 8. | 74·3 | ·04043 | 7 | 13·91 |
| 9. | 90·5 | ·04107 | 7 | 13·69 |
| 10. | 107·6 ~~107·6~~ | ·04162 | 7 | 13·51 |

| No. | Temp. | Elongation for 400 grams | No. of Observations | M. |
|---|---|---|---|---|
| 11 | 121°.9 C. | ·04209 cm. | 7 | $13.36 \times 10^{11}$ |
| 12 | 138·1 | ·04238 " | 7 | 13·27 |
| 13 | 152·7 | ·04250 | 6 | 13·23 |
| 14 | 141·5 | ·04253 | 6 | 13·22 |
| 15 | 128·4 | ·04244 | 8 | 13·25 |
| 16 | 115·0 | ·04209 | 8 | 13·36 |
| 17 | 103·2 | ·04168 | 7 | 13·49 |
| 18 | 88·3 | ·04125 | 9 | 13·63 |
| 19 | 71·6 | ·04059 | 9 | 13·85 |
| 20 | 62·9 | ·04028 | 10 | 13·96 |
| 21 | 52·6 | ·03994 | 10 | ~~13·96~~ 14·08 |
| 22 | 44·1 | ·03969 | 8 | 14·17 |
| 23 | 37·0 | ·03941 | 8 | 14·27 |
| 24 | 28·5 | ·03954 | 8 | 14·22 |
| 25 | 22·9 | ·03997 | 8 | 14·07 |
| 26. | 18·0 | ·04021 | 7 | 13·98 |

# Total load = 3·5 kilos

= 29·3 kilos per sq. mm.

## Table V.

| No. | Temp. | Elongation for 700 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 1 | 18°·1 C. | ·04024 cm. | 10 | 13·97×10¹¹ |
| 2 | 23·9 | ·03994 | 9 | 14·08 |
| 3 | 28·6 | ·03991 | 9 | 14·09 |
| 4 | 35·4 | ·03994 | 8 | 14·08 |
| 5 | 41·2 | ·04005 | 8 | 14·04 |
| 6 | 52·7 | ·04042 | 7 | 13·91 |
| 7 | 64·8 | ·04080 | 7 | 13·78 |
| 8 | 80·5 | ·04132 | 8 | 13·61 |
| 9 | 97·3 | ·04175 | 8 | 13·47 |
| 10. | 118·0 | ·04238 | 8 | 13·27 |

| No. | Temp. | Elongation for 400 grams | No. of Observations | M. |
|---|---|---|---|---|
| 11. | 135°.2 C. | ·04283 cm. | 8 | 13·13 x 10" |
| 12. | 136·4 | ·04338 | 8 | 12·96 |
| 13. | 143·6 | ·04322 | 6 | 13·01 |
| 14. | 131·8 | ·04300 | 6 | 13·08 |
| 15. | 120·3 | ·04253 | 7 | 13·22 |
| 16. | 104·7 | ·04216 | 7 | 13·34 |
| 17. | 92·6 | ·04194 | 6 | 13·41 |
| 18. | 77·9 | ·04150 | 6 | 13·55 |
| 19. | 63·1 | ·04092 | 9 | 13·74 |
| 20. | 56·5 | ·04083 | 9 | 13·77 |
| 21. | 45·2 | ·04028 | 10 | 13·96 |
| 22. | 38·6 | ·04014 | 8 | 14·01 |
| 23. | 31·8 | ·04005 | 8 | 14·04 |
| 24. | 26·7 | ·04005 | 7 | 14·04 |
| 25. | 21·3 | ·04011 | 8 | 14·02 |
| 26. | 18·0 | ·04024 | 8 | 13·97 |

Total load = 4 kilos.

= 33·5 kilos per sq. mm.

Table VI.

| No. | Temp. | Elongation for 700 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 1 | 17°·9 C. | ·04028 cm | 8 | 13·96 × 10'' |
| 2 | 22·3 | ·04035 | 8 | 13·94 |
| 3 | 31·5 | ·04059 | 9 | 13·85 |
| 4 | 40·7 | ·04080 | 10 | 13·78 |
| 5 | 55·8 | ·04107 | 7 | 13·69 |
| 6 | 71·2 | ·04140 | 9 | 13·55 |
| 7 | 88·6 | ·04187 | 7 | 13·43 |
| 8 | 107·1 | ·04253 | 9 | 13·22 |
| 9 | 129·4 | ·04297 | 9 | 13·09 |
| 10 | 146·0 | ·04341 | 8 | 12·95 |

| No. | Temp. | Elongation for 700 grams | No. of Observations | M. |
|---|---|---|---|---|
| 11 | 137°.9 C. | ·04334 cm. | 8 | $12{\cdot}97 \times 10^{11}$ |
| 12 | 123·6 | ·04288 | 9 | 13·11 |
| 13 | 105·7 | ·04235 | 8 | 13·28 |
| 14 | 92·8 | ·04219 | 9 | 13·33 |
| 15 | 76·3 | ·04165 | 10 | 13·50 |
| 16 | 62·4 | ·04122 | 10 | 13·64 |
| 17 | 51·6 | ·04104 | 9 | 13·70 |
| 18 | 38·0 | ·04066 | 9 | 13·83 |
| 19 | 29·5 | ·04056 | 8 | 13·86 |
| 20 | 24·3 | ·04043 | 8 | 13·91 |
| 21 | 17·9 | ·04028 | 10 | 13·96 |
| 22 | 10·8 | ·03973 | 10 | 14·15 |

# Table VII.

| Field. | Load in kilos per sq. mm. | Elongation for ·7 kilo | No. of Observations | M |
|---|---|---|---|---|
| ·54 | 12·5 | ·04196 cm | 8 | 13·40 $\times 10^{11}$ |
| | 15·0 | ·04170 | 8 | 13·48 |
| | 18·4 | ·04153 | 9 | 13·54 |
| | 21·0 | ·04147 | 10 | 13·56 |
| | 24·3 | ·04153 | 9 | 13·54 |
| | 29·3 | ·04223 | 9 | 13·36 |
| | 33·5 | ·04254 | 8 | 13·22 |
| | 29·3 | ·04228 | 7 | 13·30 |
| | 24·3 | ·04183 | 7 | 13·44 |
| | 21·0 | ·04165 | 6 | 13·50 |
| | 18·4 | ·04168 | 6 | 13·49 |
| | 15·0 | ·04181 | 8 | 13·45 |
| | 12·5 | ·04196 | 8 | 13·40 |

# Table VIII.

| Field | Load in kilos per sq. mm. | Elongation for ·7 kilo | No. of Observations | M. |
|---|---|---|---|---|
| 2·4 | 12·5 | ·04153 | 7 | 13·54 x 10" |
| | 15·0 | ·04089 | 7 | 13·75 |
| | 18·4 | ·04057 | 8 | 13·86 |
| | 21·0 | ·04063 | 6 | 13·84 |
| | 24·3 | ·04095 | 6 | 13·73 |
| | 29·3 | ·04170 | 5 | 13·48 |
| | 33·5 | ·04232 | 7 | 13·29 |
| | 29·3 | ·04190 | 10 | 13·42 |
| | 24·3 | ·04132 | 8 | 13·61 |
| | 21·0 | ·04112 | 9 | 13·67 |
| | 18·4 | ·04104 | 7 | 13·70 |
| | 15·0 | ·04115 | 6 | 13·66 |
| | 12·5 | ·04133 | 9 | 13·54 |

# Table IX.

| Field | Load in kilos per sq. mm. | Elongation for ·7 kilo. | No. of Observations | M. |
|---|---|---|---|---|
| 7·3 | 12·5 | ·04083 cm. | 8 | 13·77 x 10" |
| | 15·0 | ·04018 | 8 | 13·99 |
| | 18·4 | ·03957 | 9 | 14·18 |
| | 21·0 | ·03960 | 9 | 14·17 |
| | 24·3 | ·04015 | 10 | 14·00 |
| | 29·3 | ·04125 | 8 | 13·63 |
| | 33·5 | ·04199 | 7 | 13·39 |
| | 29·3 | ·04156 | 6 | 13·53 |
| | 24·3 | ·04075 | 6 | 13·80 |
| | 21·0 | ·04042 | 8 | 13·91 |
| | 18·4 | ·04039 | 8 | 13·92 |
| | 15·0 | ·04054 | 8 | 13·87 |
| | 12·5 | ·04083 | 6 | 13·77 |

# Table X.

| Field | Load in kilos per sq. mm. | Elongation for ·7 kilo. | No. of Observations | M. |
|---|---|---|---|---|
| 13·9 | 12·5 | ·03997 cm. | 10 | 14·07 × 10^11 |
| | 15·0 | ·03908 | 8 | 14·39 |
| | 18·4 | ·03837 | 8 | 14·60 |
| | 21·0 | ·03873 | 7 | 14·52 |
| | 24·3 | ·03957 | 5 | 14·21 |
| | 29·3 | ·04092 | 7 | 13·74 |
| | 33·5 | ·04187 | 9 | 13·43 |
| | 29·3 | ·04115 | 10 | 13·66 |
| | 24·3 | ·03994 | 8 | 14·08 |
| | 21·0 | ·03946 | 8 | 14·25 |
| | 18·4 | ·03944 | 8 | 14·26 |
| | 15·0 | ·03963 | 9 | 14·19 |
| | 12·5 | ·03997 | 9 | 14·07 |

# Table ~~IX~~. XI.

| Field | Load in kilos per sq. mm | Elogn. for ·7 kilo. | No. of Observations | M. |
|---|---|---|---|---|
| ~~·54~~ 20.8 | 12·5 | ·04069 cm. | 7 | 13·82 X 10" |
| | 15·0 | ·04078 | 8 | 13·99 |
| | 18·4 | ·04012 | 8 | 14·01 |
| | 21·0 | ·04063 | 9 | 13·84 |
| | 24·3 | ·04125 | 5 | 13·63 |
| | 29·3 | ·04193 | 7 | 13·41 |
| | 33·5 | ·04241 | 7 | 13·26 |
| | 29·3 | ·04226 | 6 | 13·35 |
| | 24·3 | ·04144 | 6 | 13·57 |
| | 21·0 | ·04092 | 8 | 13·74 |
| | 18·4 | ·04060 | 8 | 13·85 |
| | 15·0 | ·04048 | 10 | 13·89 |
| | 12·5 | ·04069 | 8 | 13·82 |

# Table ~~VIII~~ XII.

| Field. | Load in kilos per sq. mm. | Elongation for ·7 kilo. | No. of Observations. | M. |
|---|---|---|---|---|
| ·27·0 | 12·5 | ·04132 cm. | 8 | $13{\cdot}61 \times 10^{11}$ |
| | 15·0 | ·04122 | 7 | 13·64 |
| | 18·4 | ·04147 | 6 | 13·36 |
| | 21·0 | ·04173 | 9 | 13·47 |
| | 24·3 | ·04229 | 6 | 13·34 |
| | 29·3 | ·04267 | 8 | 13·18 |
| | 33·5 | ·04297 | 7 | 13·09 |
| | 29·3 | ·04283 | 7 | 13·13 |
| | 24·3 | ·04238 | 8 | 13·27 |
| | 21·0 | ·04196 | 9 | 13·40 |
| | 18·4 | ·04167 | 9 | 13·49 |
| | 15·0 | ·04137 | 8 | 13·59 |
| | 12·5 | ·04131 | 6 | 13·61 |

# Table ~~IX~~. XIII.

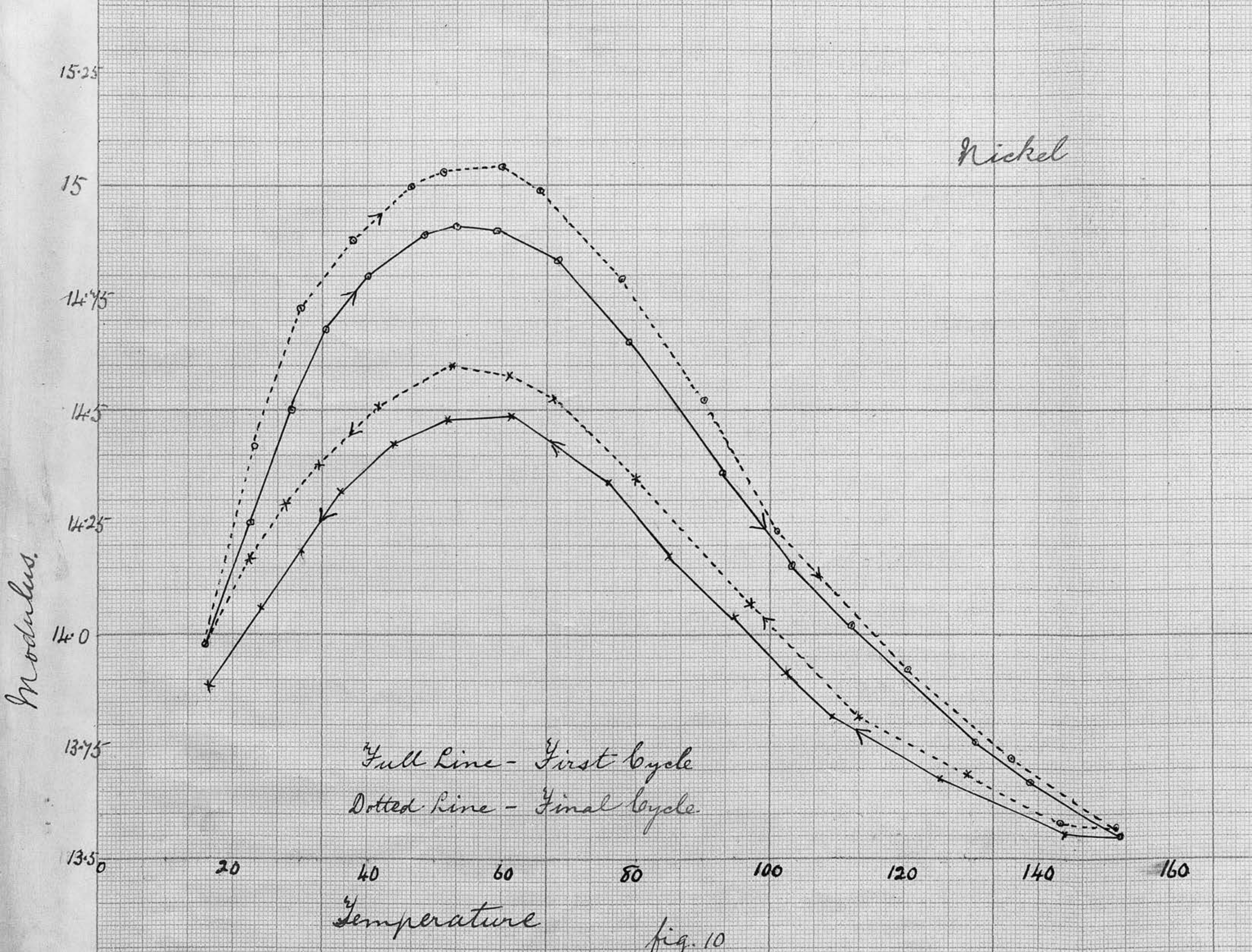
| Field. | Load in kilos per sq. mm. | Elongation for ·7 kilo. | No. of Observations | M. |
|---|---|---|---|---|
| 32·2 | 12·5 | ·04238 cm. | 7 | $13{\cdot}27 \times 10^{11}$ |
| | 15·0 | ·04244 | 6 | 13·25 |
| | 18·4 | ·04264 | 8 | 13·19 |
| | 21·0 | ·04270 | 9 | 13·17 |
| | 24·3 | ·04283 | 8 | 13·13 |
| | 29·3 | ·04300 | 9 | 13·08 |
| | 33·5 | ·04319 | 7 | 13·02 |
| | 29·3 | ·04303 | 7 | 13·07 |
| | 24·3 | ·04280 | 6 | 13·14 |
| | 21·0 | ·04270 | 6 | 13·17 |
| | 18·4 | ·04260 | 6 | 13·20 |
| | 15·0 | ·04250 | 8 | 13·23 |
| | 12·5 | ·04241 | 8 | 13·26 |

# Table XIV.

## Ordinary Heating.

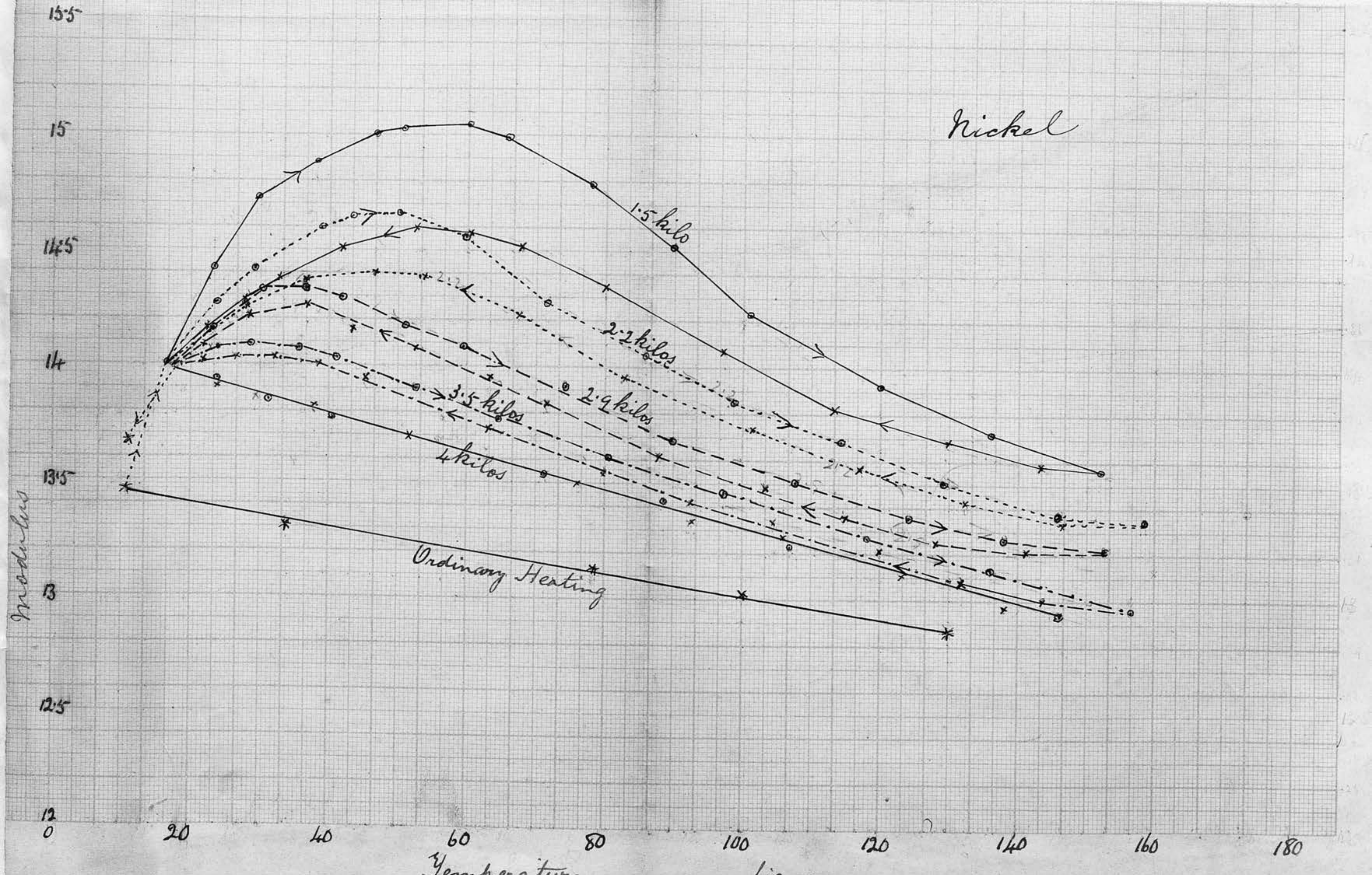
### Load = 2·5 kilos

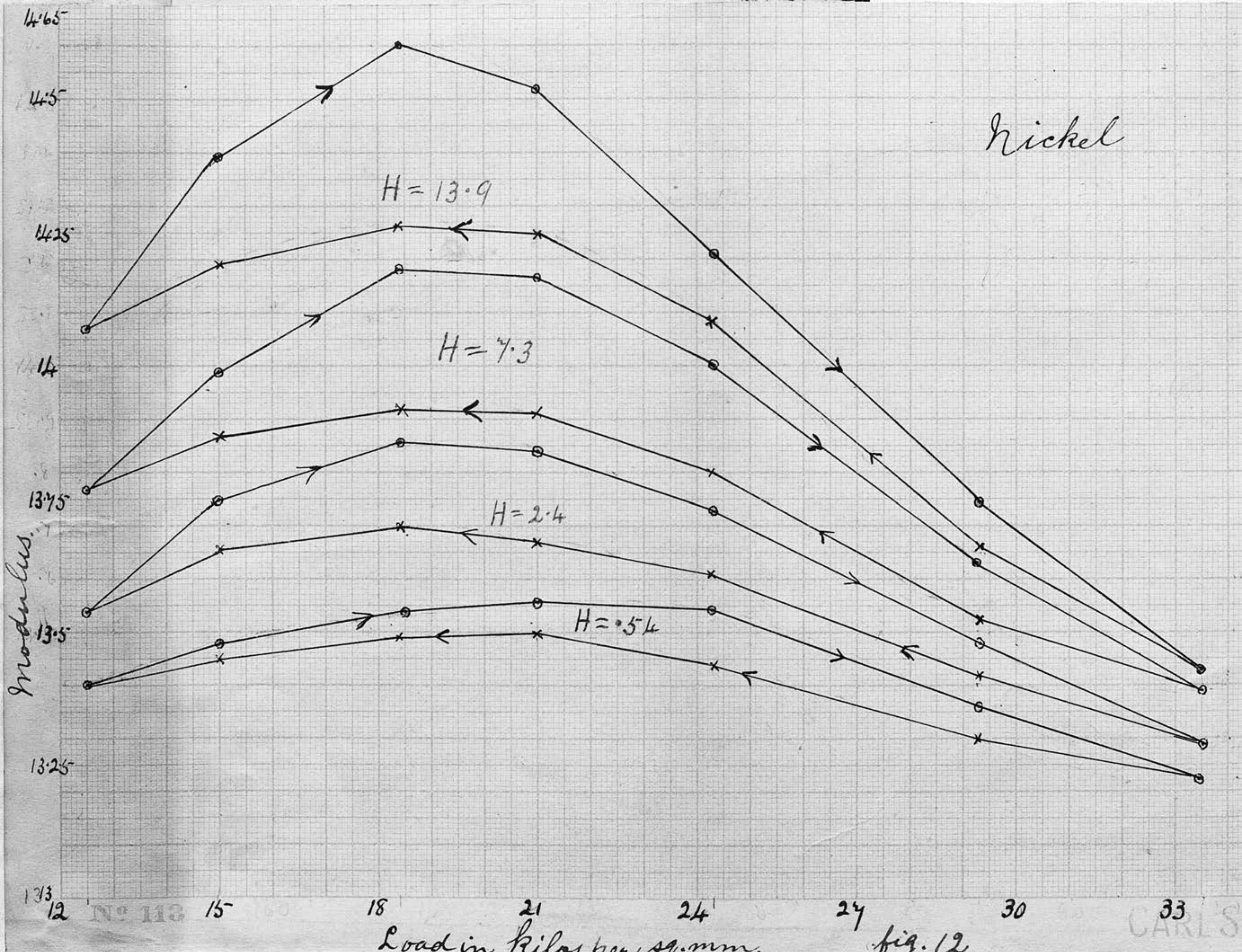
| No. | Temp. | Elongation for ·7 kilo. | No. of Observations | M. |
|---|---|---|---|---|
| 1 | 10°·7 C | ·04178 cm | 8 | $13{\cdot}46 \times 10^{11}$ |
| 2 | 35·0 | ·04214 | 8 | 13·34 |
| 3 | 78·0 | ·04283 | 6 | 13·13 |
| 4 | 100·0 | ·04319 | 6 | 13·02 |
| 5 | 130·0 | ·04358 | 6 | 12·87 |



15·25
15
14·75
14·5
14·25
14·0
13·75
13·5
0
20
40
60
80
100
120
140
160
Modulus.
Temperature
Nickel
Full Line - First Cycle
Dotted Line - Final Cycle

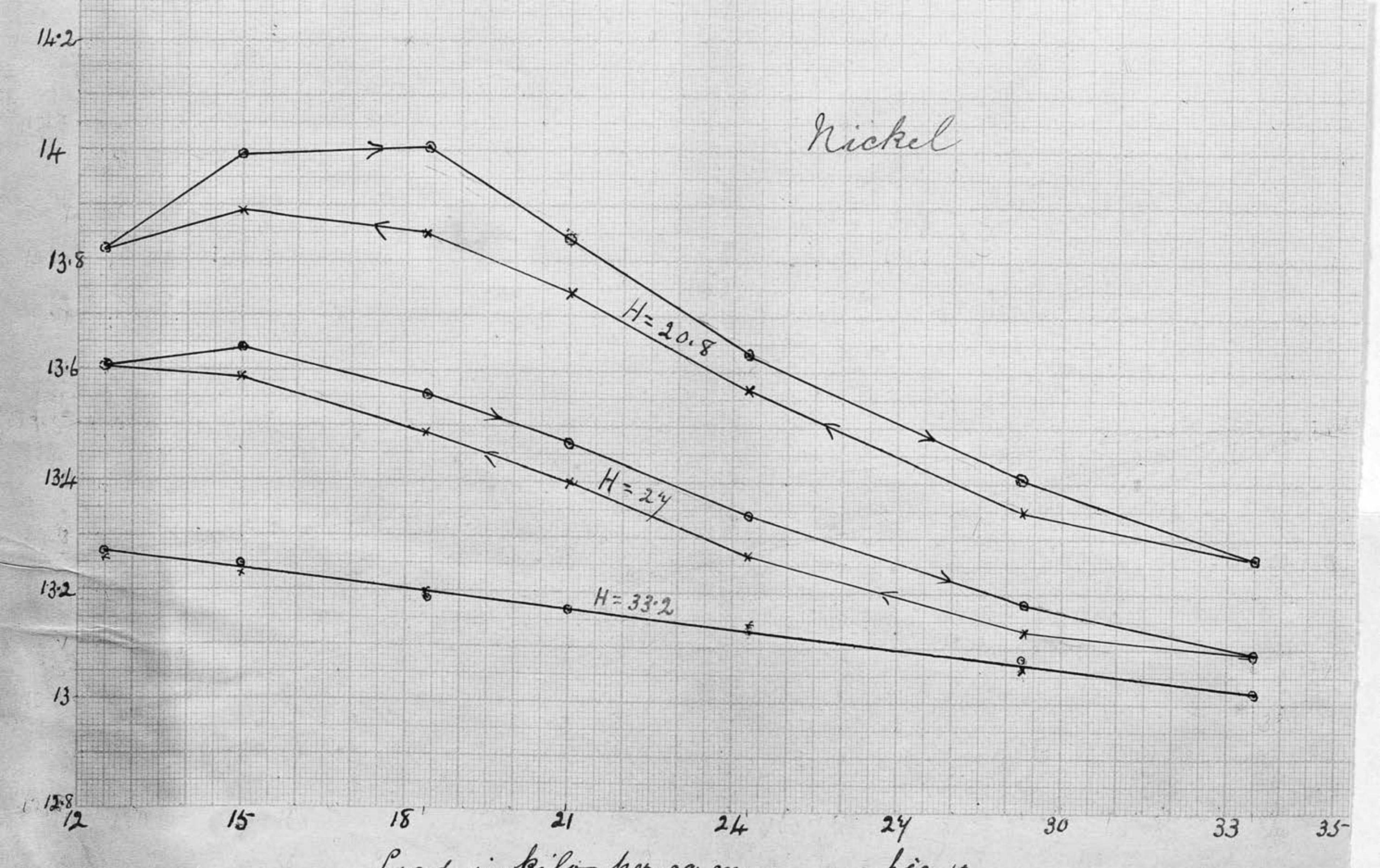
fig. 10


Nickel
1·5 kilo
2·2 kilos
2·9 kilos
3·5 kilos
4 kilos
Ordinary Heating
modulus
Temperature
15·5
15
14·5
14
13·5
13
12·5
12
0
20
40
60
80
100
120
140
160
180
fig. 11



Nickel
H = 13·9
H = 7·3
H = 2·4
H = ·54
14·65
14·5
14·25
14
13·75
13·5
13·25
13
12
15
18
21
24
27
30
33
Modulus
Load in kilos per sq. mm.

fig. 12



Nickel
14·2
14
13·8
13·6
13·4
13·2
13
12·8
12
15
18
21
24
27
30
33
35
H = 20·8
H = 24
H = 33·2
Load in kilos per sq. mm.

fig. 13

# Cobalt.

The specimen of cobalt used was a rectangular strip, as I had found it impossible to obtain a rod of a suitable size.

In the first place, the cobalt was heated in the ordinary way in the double-walled tube, the temperatures being the same as in the previous cases. The graph was a straight line, and the results are represented in fig. 15.

It was then passed through the glass tube preparatory to heating by the current, and the modulus again determined at the temperature of the room. It was found to be higher, so that heating it to 130° C. had produced an increase in the modulus, a result similar to what was obtained by Shakespear and Gray, Blyth and Dunlop in their experiments on Young's Modulus.

A weak current was then passed, with the result that the modulus was still further increased. On continuing to increase the current the modulus also increased, until a maximum was reached at about 57°C., after which increase of current caused the modulus to diminish. The heating was continued until the temperature was nearly 160°C. When the current was diminished the modulus rose, and had at first a higher value than at the corresponding stage with increasing current. A maximum was reached at about 80°C., and it was lower than that with the increasing current. This was the first cycle, and the curve did not return into itself, so that the cyclic state had not been reached. The cycle was repeated, with the result that all through the value was a little higher than in the first, and it was not until the fourth cycle had been completed that the metal attained the cyclic condition. The first and last of these experiments are given in fig. 14, the weight being 15 kilos., or 13 kilos. per sq. mm.

The cycles were repeated with increasing loads, these being 20, 25, 30, 35 and 40 kilos., that is, - 17·3, 21·6, 26·0, 30·3 and 34·6 kilos per sq. mm. respectively. The results are shown in fig.

15, and the curves show in each case the values for the final cycle only.

Finally, the current was kept constant while the load was varied, and the results of this series of experiments are shown in figs. 16 and 17. These curves are also found to be similar in form to those for iron and nickel. As they display no marked peculiarity, it is needless to enter into any detailed discussion of them. We find at first the same increase in the value as the current is raised, that a maximum is reached, and thereafter increase of current causes the modulus to diminish.

The measurements for the strip are as follows:- breadth = ·335 cm., thickness = ·0350 cm.

# Cobalt.

Length = 73·1 cms.

Area of Cross-section = ·01155 sq. cms.

Elongation Weight = 5 kilos.

Total load on wire = 15 kilos.

Load per sq. mm. = 13 kilos

## Table I. – First Cycle.

| No. | Temp. | Elongation for 5 kilos. | No. of Observations | M. |
|---|---|---|---|---|
| 1 | 13°·5 C. | ·02045 cm | 8 | $15·19 \times 10^{11}$ |
| 2 | 17·2 | ·02009 | 8 | 15·46 |
| 3 | 24·9 | ·01970 | 10 | 15·76 |
| 4 | 29·6 | ·01925 | 10 | 16·13 |
| 5 | 35·3 | ·01901 | 9 | 16·34 |

| No. | Temp. | Elongation for 5 Kilos. | No. of Observations | M. |
|---|---|---|---|---|
| 6 | 44°.7C. | ·01879 cm. | 8 | 16·53 x 10" |
| 7 | 50·1 | ·01871 | 10 | 16·60 |
| 8 | 60·8 | ·01867 | 10 | 16·63 |
| 9 | 68·4 | ·01871 | 9 | 16·60 |
| 10 | 81·0 | ·01896 | 9 | 16·38 |
| 11 | 92·6 | ·01925 | 7 | 16·13 |
| 12 | 104·5 | ·01957 | 7 | 15·87 |
| 13 | 122·3 | ·02001 | 6 | 15·53 |
| 14 | 135·1 | ·02021 | 8 | 15·37 |
| 15 | 149·7 | ·02035 | 6 | 15·26 |
| 16 | 160·4 | ·02040 | 7 | 15·22 |
| 17 | 152·1 | ·02033 | 9 | 15·28 |
| 18 | 142·2 | ·02019 | 10 | 15·38 |
| 19 | 131·5 | ·01998 | 8 | 15·54 |

| No. | Temp. | Elongation for 5 kilos. | No. of Observations | M. |
|---|---|---|---|---|
| 20 | 120°·7C. | ·01972 cm | 8 | $15{\cdot}75 \times 10^{11}$ |
| 21 | 101·3 | ·01921 | 10 | 16·17 |
| 22 | 89·4 | ·01898 | 8 | 16·36 |
| 23 | 78·9 | ·01886 | 7 | 16·47 |
| 24 | 65·8 | ·01890 | 7 | 16·43 |
| 25 | 52·3 | ·01911 | 9 | 16·25 |
| 26 | 40·5 | ·01948 | 10 | 15·94 |
| 27 | 31·6 | ·01998 | 8 | 15·54 |
| 28 | 24·3 | ·02014 | 8 | 15·42 |
| 29 | 16·2 | ·02045 | 8 | 15·19 |
| 30 | 12·6 | ·02057 | 8 | 15·10 |
| ~~31~~ | | | | |

# Table II. – Final Cycle for 15 kilos.

| No. | Temp. | Elongation for 5 Kilos | No. of Observations | M. |
|---|---|---|---|---|
| 1 | 10°.3 C. | ·02090 cm. | 8 | $14{\cdot}86 \times 10^{11}$ |
| 2 | 13·3 | ·02042 | 10 | 15·21 |
| 3 | 16·5 | ·02006 | 8 | 15·48 |
| 4 | 23·8 | ·01941 | 7 | 16·00 |
| 5 | 31·7 | ·01895 | 5 | 16·39 |
| 6 | 40·1 | ·01869 | 6 | 16·62 |
| 7 | 49·4 | ·01853 | 6 | 16·76 |
| 8 | 57·3 | ·01849 | 7 | 16·79 |
| 9 | 68·2 | ·01860 | 8 | 16·70 |
| 10 | 82·9 | ·01891 | 6 | 16·42 |
| 11 | 96·4 | ·01918 | 9 | 16·19 |
| 12 | 113·5 | ·01974 | 8 | 15·73 |

| No. | Temp. | Elongation for 3 Kilos. | No. of Observations | M. |
|---|---|---|---|---|
| 13 | 125°.6 C. | ·02002 cm. | 8 | 15·51 × 10" |
| 14 | 139·1 | ·02021 | 10 | 15·37 |
| 15 | 157·8 | ·02035 | 8 | 15·26 |
| 16 | 142·5 | ·02011 | 7 | 15·44 |
| 17 | 131·7 | ·01988 | 5 | 16·62 |
| 18 | 120·6 | ·01958 | 8 | 15·86 |
| 19 | 102·4 | ·01916 | 10 | 16·21 |
| 20 | 79·3 | ·01880 | 9 | 16·52 |
| 21 | 67·1 | ·01884 | 9 | 16·48 |
| 22 | 58·9 | ·01888 | 8 | 16·45 |
| 23 | 50·6 | ·01905 | 8 | 16·30 |
| 24 | 42·7 | ·01927 | 7 | 16·12 |
| 25 | 33·2 | ·01959 | 6 | 15·85 |
| 26. | 25·6 | ·01989 | 5 | 15·61 |
| 27 | 17·1 | ·02024 | 9 | 15·34 |
| 28 | 14·4 | ·02037 | 8 | 15·25 |
| 29 | 13·3 | ·02042 | 6 | 15·21 |

Total load = 20 kilos.

= 17·3 kilos per sq. mm.

## Table III.

| No. | Temp. | Elongation for 5 Kilos. | No. of Observations | M. |
|---|---|---|---|---|
| 1 | 12·8 C. | ·02041 cm | 8 | $15{\cdot}22 \times 10^{11}$ |
| 2 | 15·7 | ·02023 | 8 | 15·35 |
| 3 | 21·4 | ·01990 | 10 | 15·60 |
| 4 | 26·3 | ·01964 | 10 | 15·81 |
| 5 | 32·9 | ·01930 | 6 | 16·09 |
| 6 | 39·5 | ·01915 | 8 | 16·22 |
| 7 | 46·2 | ·01901 | 8 | 16·34 |
| 8 | 53·1 | ·01899 | 8 | 16·35 |
| 9 | 61·8 | ·01903 | 9 | 16·32 |
| 10 | 72·6 | ·01913 | 7 | 16·24 |

| No. | Temp. | Elongation for 5 kilos. | No. of Observations | M. |
|---|---|---|---|---|
| 11 | 84°.9 C. | ·01935 cm. | 8 | 16·05×10" |
| 12 | 98·5 | ·01969 | 8 | 15·77 |
| 13 | 116·3 | ·02006 | 9 | 15·48 |
| 14 | 130·0 | ·02026 | 9 | 15·33 |
| 15 | 143·7 | ·02039 | 7 | 15·23 |
| 16 | 158·2 | ·02046 | 6 | 15·18 |
| 17 | 147·5 | ·02037 | 9 | 15·25 |
| 18 | 136·8 | ·02026 | 8 | 15·33 |
| 19 | 123·0 | ·02005 | 8 | 15·49 |
| 20 | 111·4 | ·01981 | 8 | 15·68 |
| 21 | 101·3 | ·01959 | 5 | 15·85 |
| 22 | 85·1 | ·01930 | 7 | 16·09 |
| 23 | 72·2 | ·01924 | 9 | 16·14 |
| 24 | 63·6 | ·01927 | 8 | 16·12 |

| No. | Temp. | Elongation for 5 kilos | No. of Observations | M. |
|---|---|---|---|---|
| 25 | 51°·9C. | ·01940 cm. | 8 | 16·01×10¹¹ |
| 26 | 42·8 | ·01960 | 8 | 15·84 |
| 27 | 34·7 | ·01983 | 9 | 15·66 |
| 28 | 27·5 | ·02004 | 9 | 15·50 |
| 29 | 20·6 | ·02021 | 8 | 15·37 |
| 30 | 16·4 | ·02028 | 7 | 15·31 |
| 31 | 12·8 | ·02041 | 7 | 15·22 |

Total load = 25 Kilos.

= 21·65 kilos per sq. mm.

## Table IV.

| No. | Temp. | Elongation for 5 Kilos. | No. of Observations | M. |
|---|---|---|---|---|
| 1 | 12°·7 C. | ·02042 cms. | 10 | 15·21 x 10¹¹ |
| 2 | 16·1 | ·02033 | 8 | 15·28 |
| 3 | 22·5 | ·02005 | 9 | 15·49 |
| 4 | 29·3 | ·01988 | 7 | 15·62 |
| 5 | 35·6 | ·01970 | 6 | 15·76 |
| 6 | 40·7 | ·01957 | 6 | 15·87 |
| 7 | 44·2 | ·01952 | 9 | 15·91 |
| 8 | 51·9 | ·01951 | 8 | 15·92 |
| 9 | 59·6 | ·01956 | 8 | 15·88 |
| 10 | 72·1 | ·01973 | 6 | 15·74 |

| No. | Temp. | Elongation for 5 Kilos | No. of Observations | M. |
|---|---|---|---|---|
| 11 | 87°·8 C. | ·020~~23~~00 cm. | 7 | 15·~~36~~50 $\times 10^{11}$ |
| 12 | 103·4 | ·02023 | 8 | 15·~~18~~36 |
| 13 | 124·9 | ·02046 | 8 | 15·~~07~~18 |
| 14 | 141·2 | ·02061 | 8 | 15·07 |
| 15 | 153·8 | ·02069 | 8 | 15·01 |
| 16 | 146·5 | ·02057 | 9 | 15·10 |
| 17 | 133·1 | ·02046 | 6 | 15·18 |
| 18 | 121·7 | ·02034 | 7 | 15·27 |
| 19 | 105·6 | ·02013 | 6 | 15·43 |
| 20 | 92·3 | ·01997 | 8 | 15·55 |
| 21 | 74·2 | ·01971 | 9 | 15·76 |
| 22 | 64·7 | ·01966 | 9 | 15·80 |
| 23 | 57·9 | ·01968 | 8 | 15·78 |
| 24 | 50·4 | ·01974 | 8 | 15·73 |

| No. | Temp. | Elongation for 5 kilos. | No. of Observations | M. |
|---|---|---|---|---|
| 25 | 41°.8 C. | ·01984 cm | 5 | 15·63 × 10¹¹ |
| 26 | 33·3 | ·02006 | 7 | 15·48 |
| 27 | 26·9 | ·02021 | 6 | 15·37 |
| 28 | 21·0 | ·02033 | 8 | 15·28 |
| 29 | 15·7 | ·02040 | 7 | 15·23 |
| 30 | 12·7 | ·02042 | 7 | 15·21 |

# Total Load = 30 kilos

= 26 kilos per sq. mm.

## Table V.

| No. | Temp. | Elongation for 5 kilos | No. of Observations | M |
|---|---|---|---|---|
| 1 | 12·9°C. | ·02043 cm. | 8 | 15·20 × 10" |
| 2 | 16·1 | ·02037 | 10 | 15·25 |
| 3 | 21·8 | ·02026 | 10 | 15·33 |
| 4 | 27·6 | ·02011 | 8 | 15·44 |
| 5 | 35·7 | ·02001 | 8 | 15·52 |
| 6 | 40·5 | ·02001 | 8 | 15·52 |
| 7 | 48·3 | ·02002 | 7 | 15·51 |
| 8 | 55·6 | ·02009 | 9 | 15·46 |
| 9 | 63·8 | ·02017 | 6 | 15·40 |
| 10 | 79·2 | ·02033 | 6 | 15·28 |

| No. | Temp. | Elongation for 5 kilos. | No. of Observations. | M |
|---|---|---|---|---|
| 11 | 94·5°C. | ·02042 cm. | 8 | 15·21 × 10¹¹ |
| 12 | 110·4 | ·02053 | 10 | 15·13 |
| 13 | 122·6 | ·02061 | 9 | 15·07 |
| 14 | 137·1 | ·02071 | 7 | 14·99 |
| 15 | 154·0 | ·02077 | 6 | 14·95 |
| 16 | 143·7 | ·02071 | 6 | 14·99 |
| 17 | 131·2 | ·02062 | 7 | 15·06 |
| 18 | 119·8 | ·02053 | 8 | 15·13 |
| 19 | 105·9 | ·02043 | 6 | 15·20 |
| 20 | 88·6 | ·02032 | 7 | 15·29 |
| 21 | 72·5 | ·02020 | 7 | 15·38 |
| 22 | 60·7 | ·02009 | 6 | 15·46 |
| 23 | 51·3 | ·02000 | 6 | 15·50 |
| 24 | 43·0 | ·02010 | 9 | 15·45 |
| 25 | 35·1 | ·02017 | 10 | 15·40 |
| 26 | 29·2 | ·02026 | 8 | 15·33 |
| 27 | 22·7 | ·02033 | 8 | 15·28 |
| 28 | 16·8 | ·02039 | 8 | 15·24 |
| 29 | 12·9 | ·02043 | 8 | 15·20 |

Total Load = 35 kilos

= 30·3 kilos per sq. mm.

Table VI.

| No. | Temp. | Elongation for 5 kilos. | No. of Observations | M. |
|---|---|---|---|---|
| 1 | 13·1°C. | ·02044 cm. | 5 | $15·19 \times 10^{11}$ |
| 2 | 17·8 | ·02040 | 7 | 15·23 |
| 3 | 24·6 | ·02035 | 7 | 15·26 |
| 4 | 30·2 | ·02031 | 9 | 15·29 |
| 5 | 41·3 | ·02028 | 9 | 15·31 |
| 6 | 55·9 | ·02035 | 6 | 15·26 |
| 7 | 70·7 | ·02045 | 8 | 15·19 |
| 8 | 87·4 | ·02053 | 6 | 15·13 |
| 9 | 105·8 | ·02061 | 8 | 15·07 |
| 10 | 125·4 | ·02070 | 9 | 14·98 |

| No. | Temp. | Elongation for 5 kilos | No. of Observations | M. |
|---|---|---|---|---|
| 11 | 142·5° C. | ·02085 | 9 | 14·89×10″ |
| 12 | 159·0 | ·02093 | 8 | 14·84 |
| 13 | 141·6 | ·02084 | 8 | 14·90 |
| 14 | 131·8 | ·02076 | 8 | 14·96 |
| 15 | 114·0 | ·02062 | 9 | 15·06 |
| 16 | 97·2 | ·02054 | 8 | 15·12 |
| 17 | 78·5 | ·02043 | 7 | 15·20 |
| 18 | 60·4 | ·02033 | 6 | 15·28 |
| 19 | 53·1 | ·02028 | 6 | 15·31 |
| 20 | 42·7 | ·02029 | 7 | 15·32 |
| 21 | 33·2 | ·02034 | 8 | 15·27 |
| 22 | 21·5 | ·02041 | 8 | 15·22 |
| 23 | 17·4 | ·02042 | 9 | 15·21 |
| 24 | 13·1 | ·02044 | 9 | 15·19 |

Total Load = 40 kilos.

= 34·6 kilos per sq. mm.

Table VII.

| No. | Temp. | Elongation for 5 kilos. | No. of Observations | M. |
|---|---|---|---|---|
| 1 | 13·0°C. | ·02045 | 8 | $15·19 \times 10^{11}$ |
| 2 | 19·6 | ·02046 | 9 | 15·18 |
| 3 | 25·9 | ·02052 | 9 | 15·14 |
| 4 | 34·7 | ·02055 | 8 | 15·11 |
| 5 | 48·2 | ·02056 | 10 | 15·10 |
| 6 | 65·8 | ·02063 | 9 | 15·05 |
| 7 | 83·1 | ·02071 | 9 | 14·99 |
| 8 | 102·5 | ·02078 | 6 | 14·94 |
| 9 | 121·4 | ·02091 | 6 | 14·85 |
| 10 | 143·6 | ·02095 | 7 | 14·82 |

| No. | Temp. | Elongation for 5 kilos. | No. of Observations | M. |
|---|---|---|---|---|
| ~~12~~ 11 | 162·4°C. | ·02105 cm. | 5 | 14·75 × 10¹¹ |
| ~~13~~ 12 | 151·9 | ·02101 | 7 | 14·78 |
| ~~14~~ 13 | 134·2 | ·02090 | 8 | 14·86 |
| ~~15~~ 14 | 115·7 | ·02088 | 8 | 14·87 |
| ~~16~~ 15 | 97·3 | ·02077 | 9 | 14·95 |
| ~~17~~ 16 | 76·1 | ·02070 | 9 | 14·98 |
| ~~18~~ 17 | 60·8 | ·02063 | 10 | 15·02 |
| ~~19~~ 18 | 42·0 | ·02057 | 10 | 15·10 |
| ~~20~~ 19 | 27·6 | ·02053 | 8 | 15·13 |
| ~~21~~ 20 | 20·2 | ·02050 | 8 | 15·15 |
| ~~22~~ 21 | 13·1 | ·02045 | 6 | 15·19 |
| 22 | 10·7 | ·02066 | 5 | 15·03 |

# Table VIII.

| Yield | Load in kilos per sq. mm. | Elongation for 5 kilos | No. of Observations | M. |
|---|---|---|---|---|
| ·73 | 13·0 | ·02040 cm. | 8 | $15.22 \times 10^{11}$ |
| | 15·0 | ·02023 | 8 | 15·36 |
| | 17·3 | ·02011 | 6 | 15·~~39~~44 |
| | 21·6 | ·02012 | 6 | 15·43 |
| | 26·0 | ·02026 | 7 | 15·33 |
| | 30·3 | ·02040 | 7 | 15·22 |
| | 34·6 | ·02045 | 9 | 15·19 |
| | 30·3 | ·02033 | 9 | 15·28 |
| | 26·0 | ·02017 | 10 | 15·40 |
| | 21·6 | ·02011 | 8 | 15·44 |
| | 17·3 | ·02018 | 8 | 15·39 |
| | 15·0 | ·02027 | 6 | 15·32 |
| | 13·0 | ·02040 | 6 | 15·22 |

# Table IX.

| Field | Load in kilos per sq. mm | Elongation for 5 kilos | No. of Observations | M. |
|---|---|---|---|---|
| 3·2 | 13·0 | ·02006 cm. | 7 | 15·48×10" |
| | 15·0 | ·01963 | 9 | 15·82 |
| | 17·3 | ·01950 | 9 | 15·93 |
| | 21·6 | ·01966 | 6 | 15·80 |
| | 26·0 | ·01993 | 8 | 15·58 |
| | 30·3 | ·02014 | 8 | 15·41 |
| | 34·6 | ·02032 | 8 | 15·29 |
| | 30·3 | ·02007 | 8 | 15·47 |
| | 26·0 | ·01978 | 9 | 15·70 |
| | 21·6 | ·01951 | 9 | 15·92 |
| | 17·3 | ·01955 | 8 | 15·88 |
| | 15·0 | ·01977 | 8 | 15·71 |
| | 13·0 | ·02006 | 8 | 15·48 |

# Table X.

| Yield | Load in kilos per sq. mm | Elongation for 5 kilos. | No. of Observations | M. |
|---|---|---|---|---|
| 8·7 | 13·0 | ·01966 cm. | 9 | $15{\cdot}80 \times 10^{11}$ |
| | 15·0 | ·01912 | 9 | 16·24 |
| | 17·3 | ·01909 | 8 | 16·27 |
| | 21·6 | ·01937 | 8 | 16·03 |
| | 26·0 | ·01972 | 6 | 15·75 |
| | 30·3 | ·02005 | 6 | 15·49 |
| | 34·6 | ·02019 | 7 | 15·38 |
| | 30·3 | ·01988 | 7 | 15·62 |
| | 26·0 | ·01948 | 8 | 15·94 |
| | 21·6 | ·01937 | 5 | 16·21 |
| | 17·3 | ·01910 | 8 | 16·26 |
| | 15·0 | ·01930 | 6 | 16·09 |
| | 13·0 | ·01966 | 8 | 15·80 |

# Table XI.

| Field | Load in kilos per sq. mm. | Elongation for 5 kilos. | No. of Observations | M. |
|---|---|---|---|---|
| 16·9 | 13·0 | ·01914 cm. | 5 | $16{\cdot}23 \times 10^{11}$ |
| | 15·0 | ·01866 | 8 | 16·64 |
| | 17·3 | ·01865 | 7 | 16·65 |
| | 21·6 | ·01904 | 9 | 16·31 |
| | 26·0 | ·01954 | 7 | 15·90 |
| | 30·3 | ·01993 | 6 | 15·58 |
| | 34·6 | ·02012 | 6 | 15·43 |
| | 30·3 | ·01978 | 8 | 15·70 |
| | 26·0 | ·01928 | 8 | 16·11 |
| | 21·6 | ·01878 | 9 | 16·54 |
| | 17·3 | ·01857 | 9 | 16·72 |
| | 15·0 | ·01872 | 7 | 16·59 |
| | 13·0 | ·01914 | 6 | 16·23 |

# Table XII.

| Yield | Load in kilos per sq. mm. | Elongation for 5 kilos. | No. of Observations | M. |
|---|---|---|---|---|
| 24·1 | 13·0 | ·01960 cm. | 7 | 15·84×10" |
| | 15·0 | ·01922 | 8 | 16·16 |
| | 17·3 | ·01926 | 8 | 16·13 |
| | 21·6 | ·01962 | 9 | 15·83 |
| | 26·0 | ·01998 | 9 | 15·54 |
| | 30·3 | ·02032 | 10 | 15·29 |
| | 34·6 | ·02041 | 10 | 15·21 |
| | 30·3 | ·02024 | 8 | 15·35 |
| | 26·0 | ·01992 | 9 | 15·59 |
| | 21·6 | ·01943 | 7 | 15·98 |
| | 17·3 | ·01918 | 8 | 16·19 |
| | 15·0 | ·01927 | 8 | 16·12 |
| | 13·0 | ·01960 | 8 | 15·84 |

# Table XIII.

| Field | Load in kilos per sq. mm. | Elongation for 5 kilos. | No of Observations | M. |
|---|---|---|---|---|
| 31·6 | 13·0 | ·02034 cm. | 8 | $15 \cdot 27 \times 10^{11}$ |
| | 15·0 | ·02023 | 5 | 15·36 |
| | 17·3 | ·02034 | 7 | 15·27 |
| | 21·6 | ·02054 | 8 | 15·12 |
| | 26·0 | ·02071 | 6 | 14·99 |
| | 30·3 | ·02083 | 6 | 14·91 |
| | 34·6 | ·02087 | 7 | 14·88 |
| | 30·3 | ·02078 | 7 | 14·94 |
| | 26·0 | ·02066 | 8 | 15·03 |
| | 21·6 | ·02050 | 8 | 15·15 |
| | 17·3 | ·02027 | 6 | 15·32 |
| | 15·0 | ·02023 | 6 | 15·36 |
| | 13·0 | ·02034 | 7 | 15·27 |

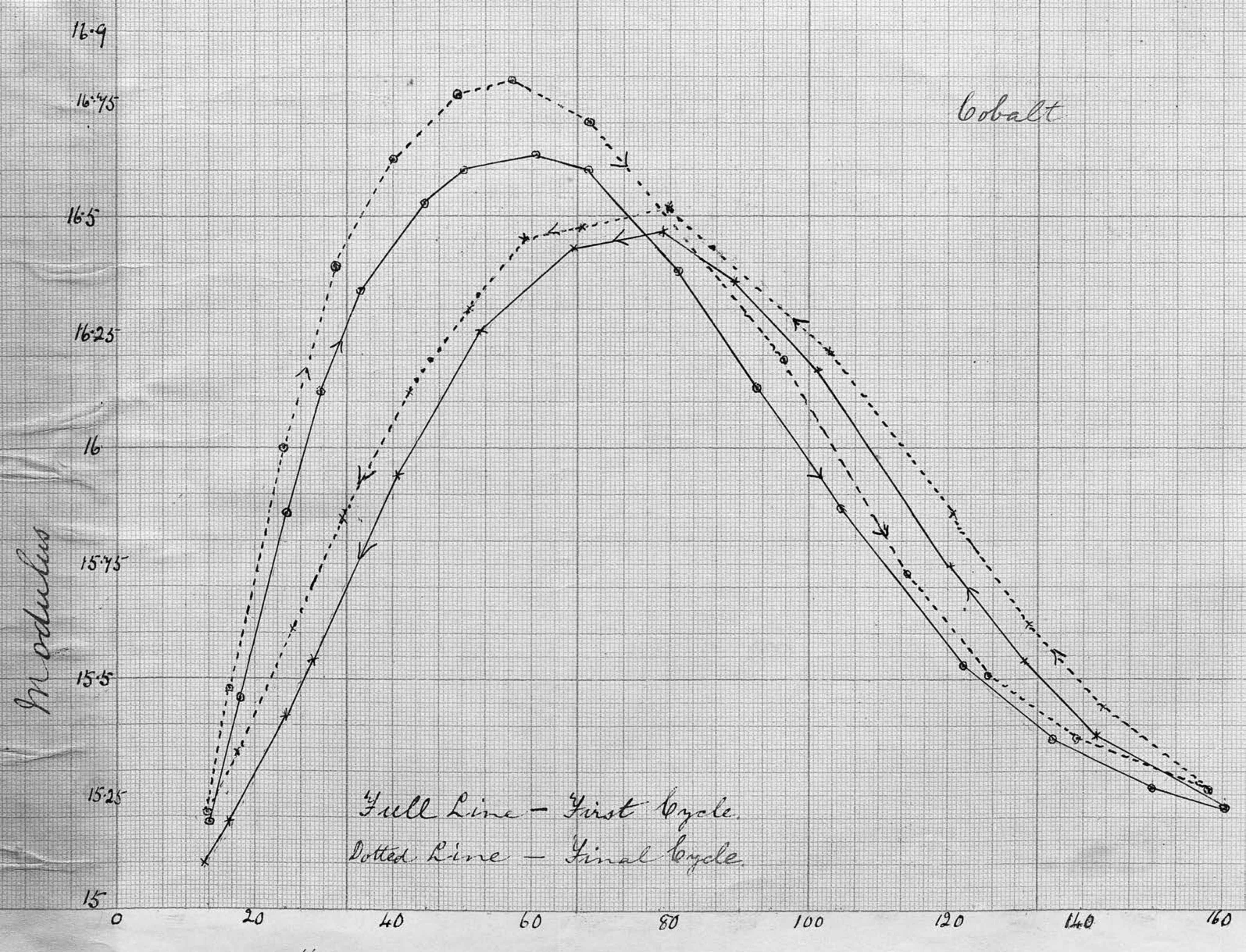
# Table XIV.

| Field | Load in kilos per sq. mm. | Elongation for 5 kilos. | No. of Observations | M. |
|---|---|---|---|---|
| 35.4 | 13.0 | .02042 cm. | 7 | $15.21 \times 10^{11}$ |
| | 15.0 | .02046 | 8 | 15.18 |
| | 17.3 | .02053 | 7 | 15.13 |
| | 21.6 | .02065 | 9 | 15.04 |
| | 26.0 | .02077 | 6 | 14.95 |
| | 30.3 | .02085 | 6 | 14.89 |
| | 34.6 | .02098 | 5 | 14.80 |
| | 30.3 | .02086 | 5 | 14.88 |
| | 26.0 | .02074 | 6 | 14.97 |
| | 21.6 | .02064 | 8 | 15.05 |
| | 17.3 | .02053 | 8 | 15.13 |
| | 15.0 | .02047 | 7 | 15.17 |
| | 13.0 | .02043 | 9 | 15.20 |

# Table XV.

## Ordinary Heating
## Load = 25 kilos.

| No. ~~Temp.~~ | Temp. | Elongation for 5 kilos. | No. of Observations | M. |
|---|---|---|---|---|
| 1 | 11·2°C | ·02100 cm. | 8 | $14{\cdot}79 \times 10^{11}$ |
| 2 | 35·0 | ·02103 | 7 | 14·76 |
| 3 | 78·0 | ·02105 | 9 | 14·75 |
| 4 | 100·0 | ·02108 | 6 | 14·73 |
| 5 | 130·0 | ·02111 | 8 | 14·71 |



16·9
16·75
16·5
16·25
16
15·75
15·5
15·25
15
0
20
40
60
80
100
120
140
160
Modulus
Temperature
Cobalt
Full Line - First Cycle.
Dotted Line - Final Cycle.


fig. 14

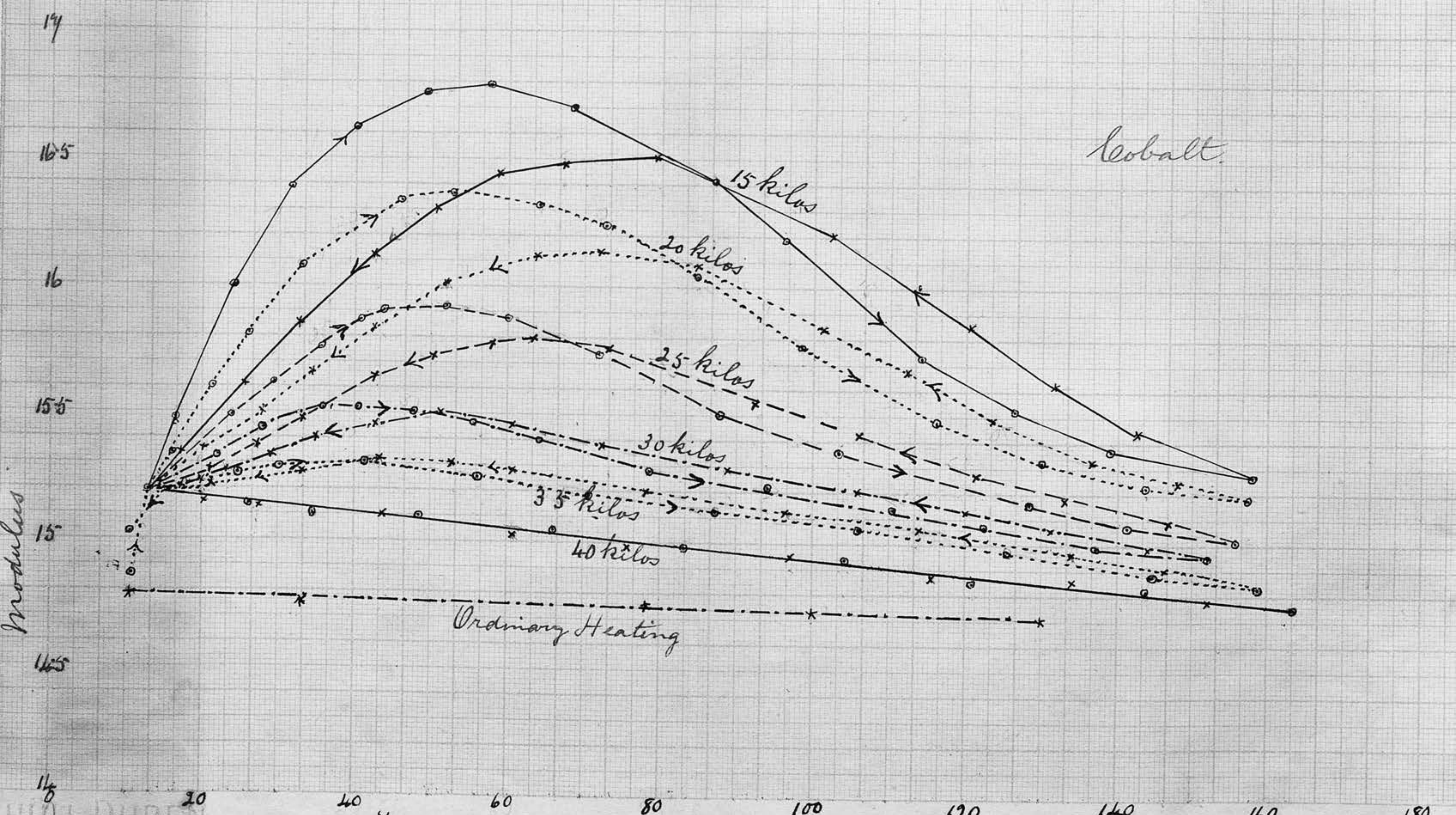

Cobalt
15 kilos
20 kilos
25 kilos
30 kilos
35 kilos
40 kilos
Ordinary Heating
Modulus
Temperature
17
16.5
16
15.5
15
14.5
14
0
20
40
60
80
100
120
140
160
180

fig. 15

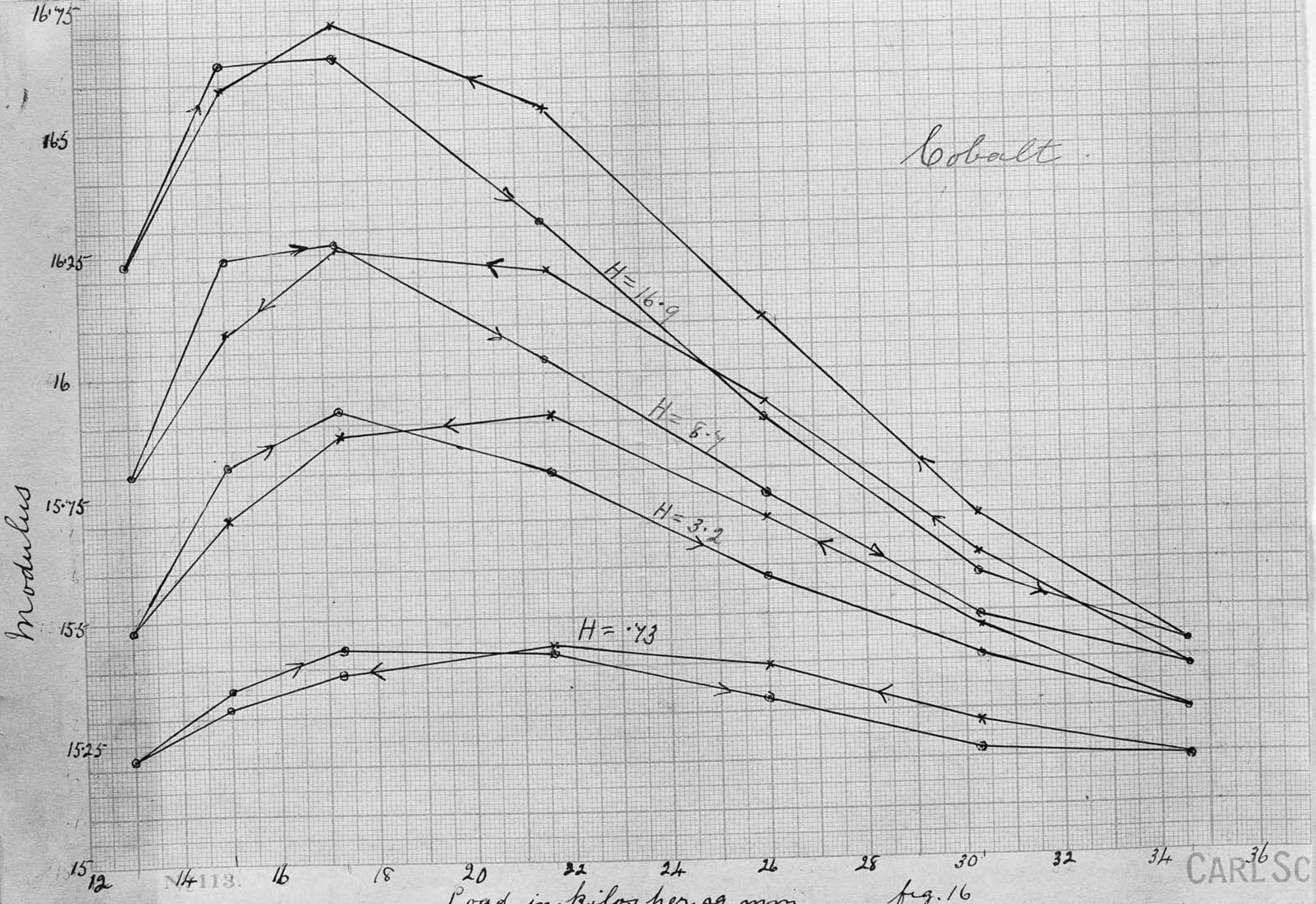
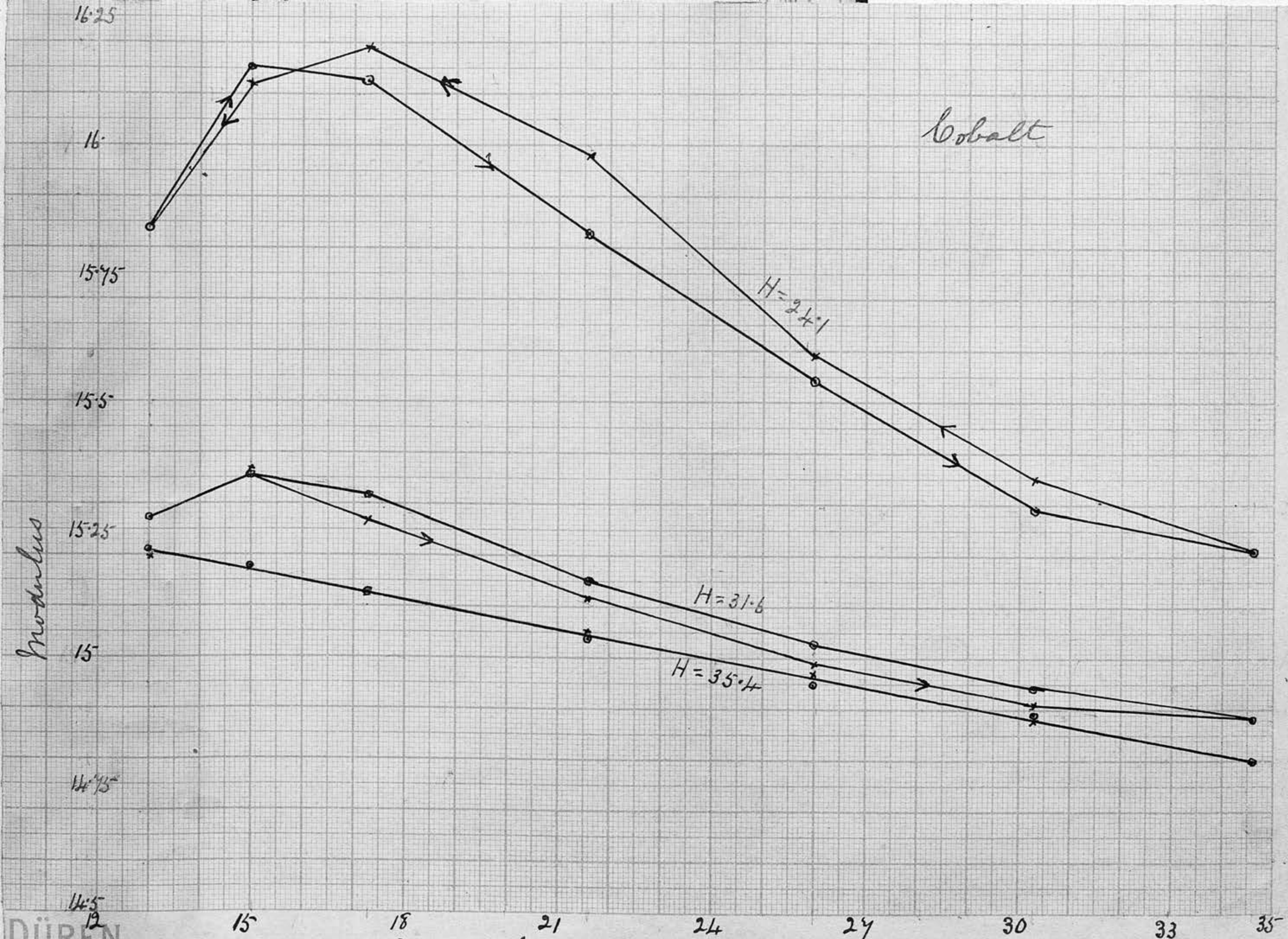


fig. 16

N 4113.

CARL SC



Cobalt
H = 24·1
H = 31·6
H = 35·4
Modulus
16·25
16·
15·75
15·5
15·25
15·
14·75
14·5
12
15
18
21
24
27
30
33
35
Load in kilos per sq. mm.

fig. 17

# Copper.

The course of the experiments on copper was exactly the same as that already described for the other metals.

The results are represented on fig. 18 ~~17~~, ~~and~~. The curves show how the modulus varies as the current is increased, also how the maximum values get less and less as the load is increased, and how with increase of load the maximum is reached at an earlier stage in the cyclic process.

The curves resemble those for steel and cobalt, as the curve for diminishing current lies at first above that for increasing current, attains a maximum for the diminishing current, which is lower than that for the increasing current, and, finally, has a value less than what it was for increasing current.

The results for those experiments in which the current was constant and the load altered are shown in figs. ~~18~~ 19 and ~~19~~ 20; but a minute description of them would merely be a repetition of points already mentioned in the other metals.

# Copper.

Length = 98·15 cms.

Area of Cross-section = ·0006026 sq. cms.

Elongation Weight = 300· grams.

Total Load on Wire = 1·0 kilo.

Load per sq. mm. = ~~[illegible]~~ 16·6 kilos.

## Table IV

| No. | Temp. | Elongation for 300 grams | No. of Observations | M. |
|---|---|---|---|---|
| 1 | 16·9°C. | ·04320 cm. | 7 | 11·10×10¹¹ |
| 2 | 20·2 | ·04192 | 8 | 11·44 |
| 3 | 25·4 | ·04064 | 8 | 11·80 |
| 4 | 29·8 | ·03995 | 9 | 12·01 |
| 5 | 33·0 | ·03963 | 9 | 12·10 |

| No. | Temp. | Elongation for 300 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 6 | 35·3°C | ·03960 cm | 8 | 12·11 × 10" |
| 7 | 40·5 | ·03990 | 9 | 12·02 |
| 8 | 48·7 | ·04039 | 7 | 11·87 |
| 9 | 55·3 | ·04092 | 7 | 11·72 |
| 10 | 61·6 | ·04120 | 6 | 11·64 |
| 11 | 70·1 | ·04174 | 9 | 11·49 |
| 12 | 79·8 | ·04218 | 9 | 11·37 |
| 13 | 91·2 | ·04263 | 8 | 11·25 |
| 14 | 101·5 | ·04287 | 8 | 11·19 |
| 15 | 112·6 | ·04313 | 10 | 11·12 |
| 16 | 124·7 | ·04337 | 8 | 11·06 |
| ~~18~~ 17 | 117·4 | ·04305 | 6 | 11·14 |
| ~~19~~ 18 | 108·8 | ·04278 | 8 | 11·21 |
| ~~20~~ 19 | 97·9 | ·04248 | 8 | 11·29 |

| No. | Temp. | Elongation for 300 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 20 | 85.4°C. | ·04166 cm | 8 | $11{\cdot}51 \times 10^{11}$ |
| ~~22~~ 21 | 76·3 | ·04126 | 9 | 11·62 |
| 22 | 64·0 | ·04064 | 9 | 11·80 |
| ~~24~~ 23 | 59·8 | ·04046 | 10 | 11·85 |
| 24 | 52·1 | ·04039 | 10 | 11·87 |
| 25 | 45·2 | ·04067 | 7 | 11·79 |
| 26 | 38·6 | ·04105 | 6 | 11·68 |
| ~~28~~ 27 | 34·5 | ·04145 | 8 | 11·57 |
| 28 | 27·7 | ·04188 | 8 | 11·45 |
| ~~30~~ 29 | 23·4 | ·04240 | 8 | 11·31 |
| 30 | 16·9 | ·04320 | 8 | 11·10 |

Total Load = 1·2 kilos.

= 19·9 kilos per sq. mm.

Table V.

| No. | Temp. | Elongation for 300 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 1 | 17·2°C | ·04317 cm. | 6 | $11{\cdot}11 \times 10^{11}$ |
| 2 | 19·6 | ·04260 | 8 | 11·26 |
| 3 | 24·3 | ·04203 | 8 | 11·41 |
| 4 | 28·0 | ·04174 | 6 | 11·49 |
| 5 | 33·1 | ·04166 | 7 | 11·51 |
| 6 | 40·5 | ·04177 | 8 | 11·48 |
| 7 | 51·7 | ·04225 | 8 | 11·35 |
| 8 | 59·9 | ·04244 | 10 | 11·30 |
| 9 | 71·6 | ·04287 | 8 | 11·19 |
| 10 | 83·4 | ·04305 | 8 | 11·14 |
| 11 | 96·3 | ·04325 | 7 | 11·09 |
| 12 | 108·7 | ·04344 | 6 | 11·04 |
| 13 | 117·2 | ·04352 | 6 | 11·02 |
| 14 | 125·8 | ·04359 | 8 | 11·00 |

~~#19~~

| No. | Temp. | Elongation for 300 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 15 | 116.5°C | .04344 cm. | 8 | $11.04 \times 10^{11}$ |
| 16 | 104.6 | .04313 | 8 | 11.12 |
| 17 | 91.7 | .042~~78~~81 | 9 | 11.20 |
| 18 | 77.2 | .04248 | 9 | 11.29 |
| 19 | 65.9 | .04214 | 6 | 11.38 |
| 20 | 58.3 | .04188 | 7 | 11.45 |
| 21 | 53.0 | .04184 | 6 | 11.46 |
| 22 | 42.8 | .04203 | 8 | 11.41 |
| 23 | 35.1 | .04233 | 9 | 11.33 |
| 24 | 26.4 | .04260 | 10 | 11.26 |
| 25 | 21.5 | .04287 | 8 | 11.19 |
| 26 | 17.3 | .04317 | 8 | 11.11 |

Total Load = 1·4 kilos
= 23·2 kilos per sq. mm.

Table VI.

| No. | Temp. | Elongation for 300 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 1 | 17·2°C | ·04317 cm | 8 | $11{\cdot}11 \times 10^{11}$ |
| 2 | 22·8 | ·04260 | 8 | 11·26 |
| 3 | 26·1 | ·04248 | 10 | 11·29 |
| 4 | 33·4 | ·04244 | 9 | 11·30 |
| 5 | 42·6 | ·04260 | 7 | 11·26 |
| 6 | 55·7 | ·04294 | 8 | 11·17 |
| 7 | 69·9 | ·04317 | 8 | 11·11 |
| 8 | 84·2 | ·04344 | 6 | 11·04 |
| 9 | 103·0 | ·04366 | 7 | 10·98 |
| 10 | 117·5 | ·04395 | 7 | 10·91 |

| No. | Temp. | Elongation for 300 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 11 | 126·3°C | ·04402 cm. | 8 | 10·89×10¹¹ |
| 12 | 114·8 | ·04378 | 8 | 10·95 |
| 13 | 105·1 | ·04356 | 9 | 11·01 |
| 14 | 91·7 | ·04337 | 9 | 11·06 |
| 15 | 80·6 | ·04305 | 10 | 11·14 |
| 16 | 63·3 | ·04270 | 8 | 11·23 |
| 17 | 51·7 | ·04255 | 7 | 11·27 |
| 18 | 40·2 | ·04269 | 6 | 11·24 |
| 19 | 32·5 | ·04275 | 6 | 11·22 |
| 20 | 25·8 | ·04298 | 6 | 11·16 |
| 21 | 20·9 | ·04305 | 7 | 11·14 |
| 22 | 17·2 | ·04317 | 7 | 11·11 |

# Table VII.

| Field. | Load in kilos per sq. mm. | Elongation for 300 grams | No. of Observations | M. |
|---|---|---|---|---|
| ·85 | 13·3 | ·04313 cm. | 10 | $11{\cdot}12 \times 10^{11}$ |
| | 14·9 | ·04218 | 8 | 11·37 |
| | 16·6 | ·04185 | 9 | 11·46 |
| | 19·9 | ·04199 | 9 | 11·42 |
| | 23·2 | ·04248 | 8 | 11·29 |
| | 26·5 | ·04313 | 7 | 11·12 |
| | 23·2 | ·04229 | 6 | 11·34 |
| | 19·9 | ·04218 | 6 | 11·37 |
| | 16·6 | ·04225 | 8 | 11·35 |
| | 14·9 | ·04259 | 8 | 11·26 |
| | 13·3 | ·04313 | 6 | 11·12 |

# Table VIII

| Field | Load in kilos per sq mm. | Elongation for 300 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 5·7 | 13·3 | ·04203 cm. | 6 | 11·41 |
| | 14·9 | ·03983 | 6 | 12·04 |
| | 16·6 | ·03930 | 8 | 12·20 |
| | 19·9 | ·04012 | 8 | 11·95 |
| | 23·2 | ·04148 | 8 | 11·56 ~~11·29~~ |
| | 26·5 | ·04248 | 7 | 11·~~65~~29 |
| | 23·2 | ·04116 | 7 | 12·~~02~~15 |
| | 19·9 | ·03993 | 9 | 11·~~74~~97 |
| | 16·6 | ·04016 | 10 | 11·~~77~~94 |
| | 14·9 | ·04074 | 8 | 11·77 |
| | 13·3 | ·04203 | 7 | 11·41 |

# Table IX.

| Field. | Load in kilos per sq. mm. | Elongation for 300 grams | No. of Observations | M |
|---|---|---|---|---|
| 11·3 | 13·3 | ·03947 cm. | 6 | 12·13 x 10$^{11}$ |
| | 14·9 | ·03749 | 8 | 12·79 |
| | 16·6 | ·03700 | 8 | 12·96 |
| | 19·9 | ·03776 | 10 | 12·70 |
| | 23·2 | ·04046 | 10 | 11·85 |
| | 26·5 ~~19·9~~ | ·04207 | 8 | 11·40 |
| | 23·2 | ·03974 | 6 | 12·07 |
| | 19·9 | ·03752 | 7 | 12·78 |
| | 18·2 | ·03714 | 7 | 12·91 |
| | 16·6 | ·03769 | 9 | 12·72 |
| | 14·9 | ·03833 | 8 | 12·48 |
| | 13·3 | ·03947 | 9 | 12·15 |

# Table X.

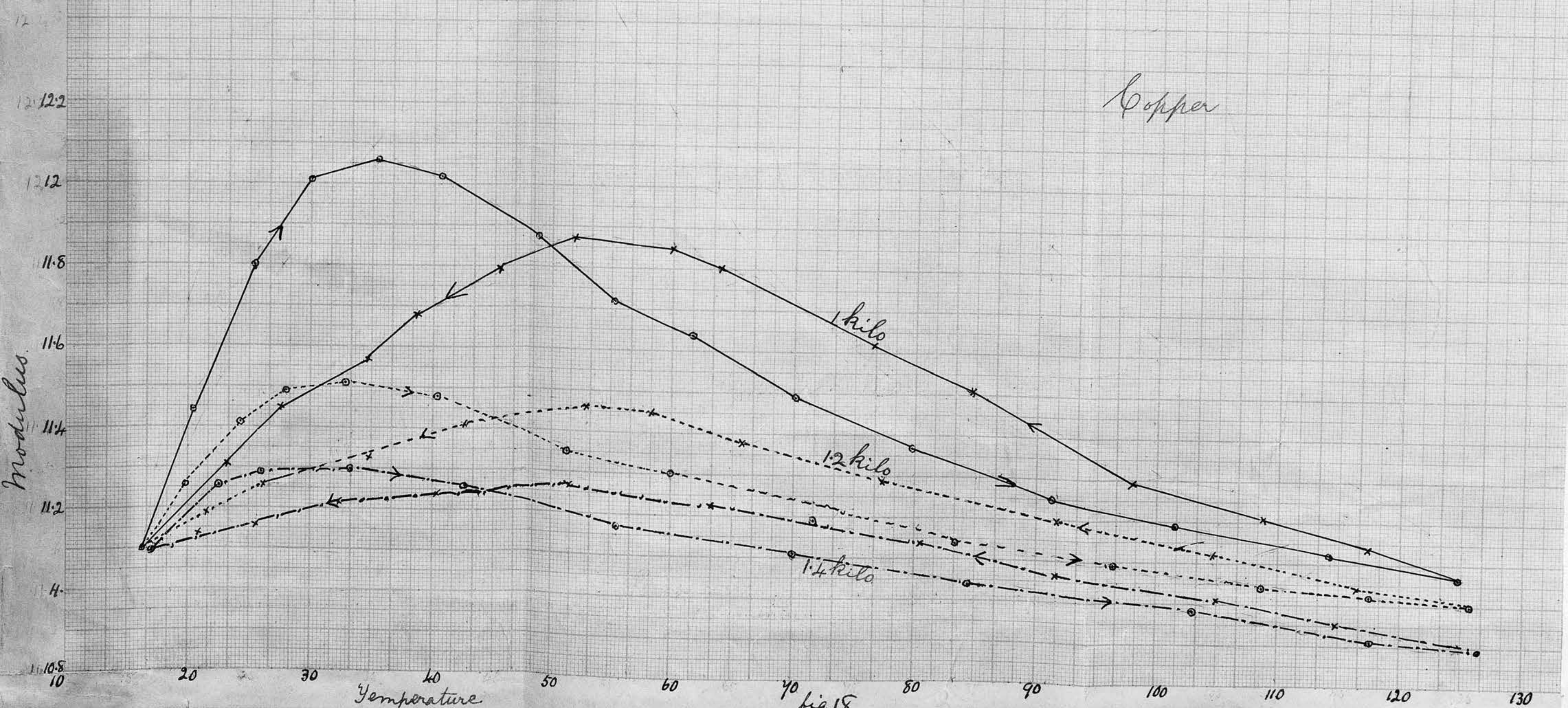
| Field | Load in Kilos per sq. mm. | Elongation for 300 grams. | No. of Observations | M |
|---|---|---|---|---|
| 20.8 | 13.3 | ·04003 cm. | 8 | $11.97 \times 10^{11}$ |
| | 14.9 | ·03880 | 10 | 12.36 |
| | 16.6 | ·03886 | 8 | 12.34 |
| | 19.9 | ·03993 | 7 | 12.01 |
| | 23.2 | ·04119 | 6 | 11.64 |
| | 26.5 | ·04232 | 5 | 11.33 |
| | 23.2 | ·04081 | 8 | 11.75 |
| | 19.9 | ·03957 | 8 | 12.12 |
| | 16.6 | ·03909 | 7 | 12.27 |
| | 14.9 | ·03944 | 7 | 12.16 |
| | 13.3 | ·04005 | 8 | 11.97 |

# Table XI.

| Field. | Load in kilos per sq. mm. | Elongation for 300 grams | No. of Observations | M. |
|---|---|---|---|---|
| 32·6 | 13·3 | ·04181 cm. | 8 | $11{\cdot}47 \times 10^{11}$ |
| | 14·9 | ·04141 | 8 | 11·58 |
| | 16·6 | ·04159 | 6 | 11·53 |
| | 19·9 | ·04214 | 6 | 11·38 |
| | 23·2 | ·04267 | 9 | 11·24 |
| | 26·5 | ·04305 | 9 | 11·14 |
| | 23·2 | ·04244 | 7 | 11·30 |
| | 19·9 | ·04181 | 7 | 11·47 |
| | 16·6 | ·04141 | 6 | 11·58 |
| | 14·9 | ·04155 | 4 | 11·54 |
| | 13·3 | ·04181 | 8 | 11·47 |

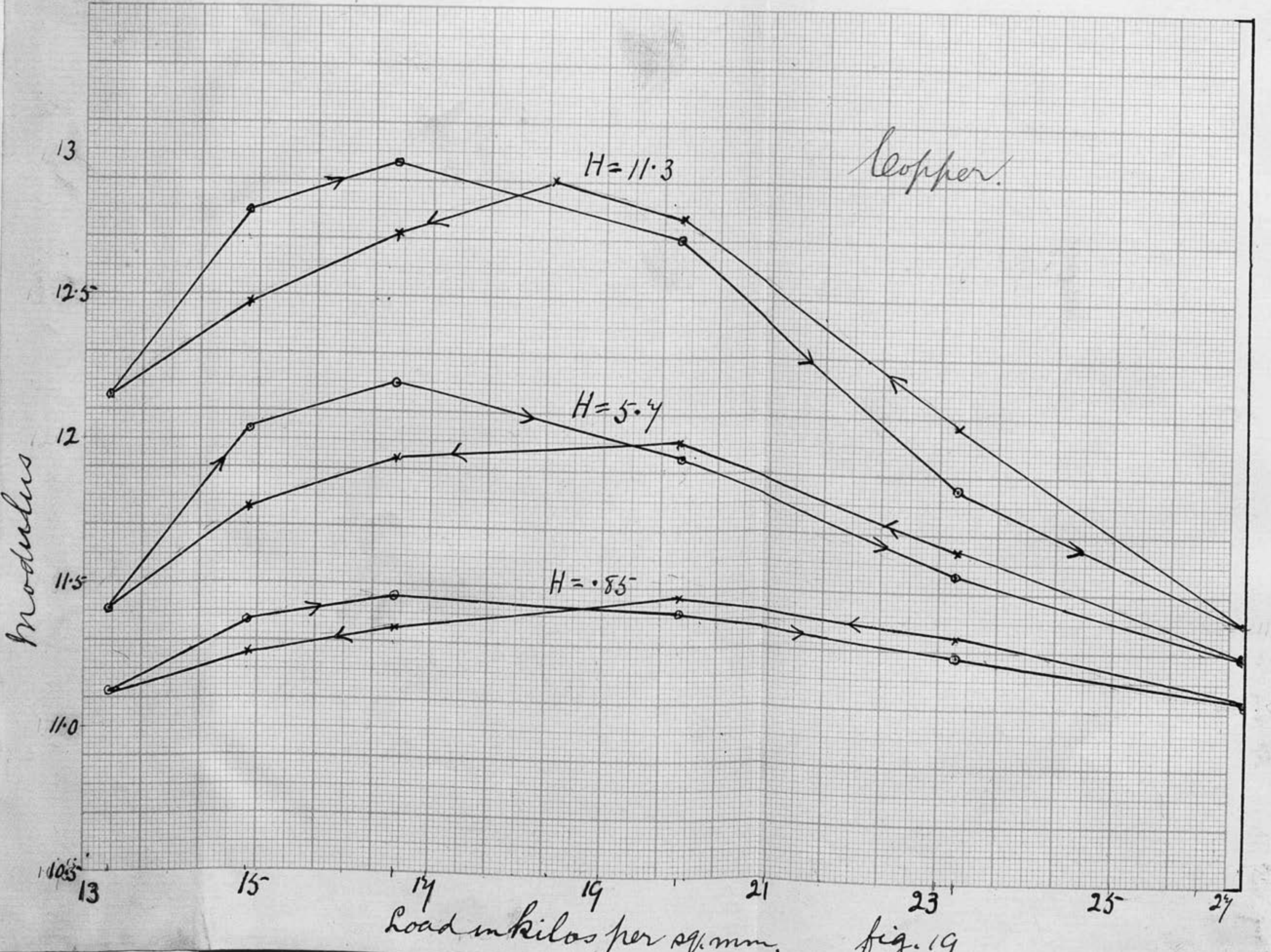
# Table XII.

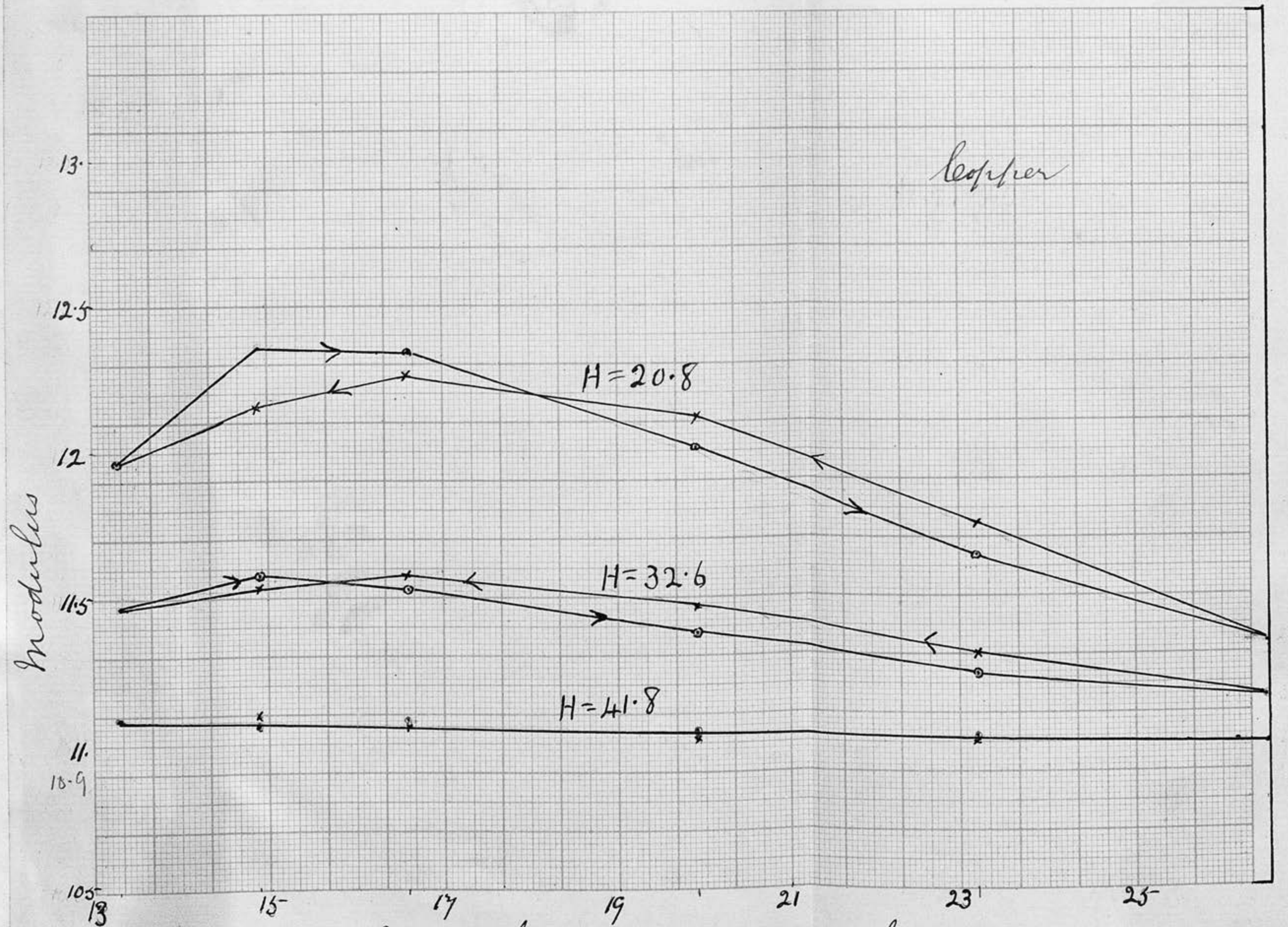
| Field. | Load in kilos per sq. mm. | Elongation for 300 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 41·8 | 13·3 | ·04325 cm | 9 | $11{\cdot}09 \times 10^{11}$ |
| | 14·9 | ·04333 | 8 | 11·07 |
| | 16·6 | ·04329 | 8 | 11·08 |
| | 19·9 | ·04344 | 10 | 11·04 |
| | 23·2 | ·04352 | 8 | 11·02 |
| | 26·5 | ·04362 | 6 | 10·99 |
| | 23·2 | ·04356 | 8 | 11·01 |
| | 19·9 | ·04352 | 7 | 11·02 |
| | 16·6 | ·04337 | 7 | 11·06 |
| | 14·9 | ·04320 | 9 | 11·10 |
| | 13·3 | ·04320 | 9 | 11·10 |



Copper
1 kilo
1·2 kilo
1·4 kilo
Modulus
Temperature
12·2
12
11·8
11·6
11·4
11·2
11·0
10·8
10
20
30
40
50
60
70
80
90
100
110
120
130

fig. 18


Copper.
H = 11·3
H = 5·4
H = ·85
Modulus
13
12·5
12
11·5
11·0
10·5
13
15
17
19
21
23
25
27
Load in kilos per sq. mm.
fig. 19


Copper
H=20·8
H=32·6
H=41·8
Modulus
13·
12·5
12
11·5
11.
10·9
10·5
13
15
17
19
21
23
25
Load in kilos per sq. mm.
fig. 20

## Platinum.

The results for platinum are shown in fig 21. These curves have marked differences from the others; there is a smaller rate of increase as the current rises, and, after the maximum has been attained, the rate of decrease is more rapid than the rate of increase. With diminishing current there is at first a fall, then a rapid increase to a maximum, and, finally, ~~a~~ diminution of about the same rate. The peculiarity platinum exhibits in the rapid rise with diminishing current, is found to be greatly influenced by increase of load; so that it would appear as if the molecular arrangements, which give the wire its power to resist extension, were not formed when the load was increased.

The curves obtained from the experiments with constant field and varying load are shown in figs. 22 and 23. They show the same characteristic rise + fall, but not to the same degree as in the other method of experiment.

# Platinum.

Length = 62·12 cms.

Area of Cross-section = ·0007548 sq. cms.

Elongation Weight = 500· grams.

Total Load on Wire = 1·2 kilos

Load per sq. mm. = 15·9 kilos

## Table V.

| No. | Temp. | Elongation for 500 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 1 | 21·9°C | ·03185 cm | 8 | $12{\cdot}68 \times 10^{11}$ |
| 2 | 29·2 | ·03142 | 8 | 12·85 |
| 3 | 40·6 | ·03090 | 8 | 13·07 |
| 4 | 51·3 | ·03034 | 9 | 13·31 |
| 5 | 65·0 | ·02974 | 8 | 13·59 |

| No. | Temp. | Elongation for 500grams. | No. of Observations | M. |
|---|---|---|---|---|
| 6 | 82·1°C | ·02871 cm. | 8 | 14·08 × 10" |
| 7 | 97·8 | ·02755 | 8 | 14·67 |
| 8 | 104·5 | ·02711 | 7 | 14·91 |
| 9 | 113·3 | ·02716 | 6 | 14·88 |
| 10 | 120·7 | ·02763 | 8 | 14·63 |
| 11 | 131·4 | ·02871 | 8 | 14·06 |
| 12 | 145·0 | ·03034 | 10 | 13·31 |
| 13 | 157·3 | ·03185 | 9 | 12·68 |
| 14 | 148·1 | ·03257 | 9 | 12·41 |
| 15 | 137·4 | ·03234 | 8 | 12·50 |
| 16 | 129·2 | ·03203 | 8 | 12·62 |
| 17 | 120·7 | ·03126 | 8 | 12·93 |
| 18 | 110·5 | ·02929 | 8 | 13·80 |
| 19 | 99·6 | ·02611 | 8 | 15·48 |

| No. | Temp. | Elongation for 500 grams | No. of Observations | M. |
|---|---|---|---|---|
| 20 | 90.8°C | ·02454 cm. | 8 | $16.47 \times 10^{11}$ |
| 21 | 87.0 | ·02431 | 8 | 16.63 |
| 22 | 79.9 | ·02463 | 7 | 16.41 |
| 23 | 68.7 | ·02703 | 6 | 14.95 |
| 24 | 56.6 | ·02829 | 6 | 14.29 |
| 25 | 47.4 | ·02942 | 8 | 13.74 |
| 26 | 35.1 | ·03072 | 9 | 13.16 |
| 27 | 27.5 | ·03128 | 8 | 12.92 |
| 28 | 21.9 | ·03185 | 8 | 12.68 |

Total Load = 1·5 kilos.

= 19·9 kilos per sq. mm.

Table VI.

| No. | Temp. | Elongation for 500 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 1 | 22·0°C. | ·03185 cm. | 8 | $12{\cdot}68 \times 10^{11}$ |
| 2 | 28·6 | ·03155 | 8 | 12·80 |
| 3 | 39·5 | ·03121 | 7 | 12·95 |
| 4 | 48·9 | ·03076 | 6 | 13·14 |
| 5 | 60·3 | ·03028 | 8 | 13·35 |
| 6 | 77·4 | ·02916 | 9 | 13·86 |
| 7 | 91·7 | ·02849 | 8 | 14·19 |
| 8 | 100·6 | ·02792 | 8 | 14·48 |
| 9 | 111·2 | ·02770 | 8 | 14·59 |
| 10 | 123·8 | ·02837 | 9 | 14·25 |
| 11 | 132·1 | ·02920 | 10 | 13·84 |

| No. | Temp. | Elongation for 500 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 12 | 144·7°C. | ·03070 cm. | 8 | $13.17 \times 10^{11}$ |
| 13 | 158·0 | ·03203 | 8 | 12·62 |
| 14 | 151·2 | ·03263 | 8 | 12·39 |
| 15 | 144·9 | ·03260 | 8 | 12·40 |
| 16 | 137·3 | ·03249 | 10 | 12·44 |
| 17 | 130·1 | ·03241 | 10 | 12·47 |
| 18 | 121·5 | ·03160 | 9 | 12·79 |
| 19 | 113·6 | ·03023 | 9 | 13·35 |
| 20 | 105·2 | ·02841 | 8 | 14·23 |
| 21 | 98·3 | ·02724 | 6 | 14·84 |
| 22 | 89·4 | ·02663 | 8 | 15·18 |
| 23 | 72·7 | ·02750 | 8 | 14·70 |
| 24 | 59·9 | ·02871 | 8 | 14·08 |
| 25 | 45·8 | ·02992 | 8 | 13·51 |
| 26 | 35·3 | ·03081 | 9 | 13·12 |
| 27 | 26·2 | ·03148 | 7 | 12·84 |
| 28 | 22·0 | ·03185 | 8 | 12·68 |

Total Load = 1·8 kilos.

= 23·8 kilos per sq. mm.

Table VII.

| No. | Temp. | Elongation for 500 grams. | No. of Observations. | M. |
|---|---|---|---|---|
| 1 | 22·3°C. | ·03193 cm. | 8 | $12.66 \times 10^4$ |
| 2 | 29·5 | ·03168 | 8 | 12·76 |
| 3 | 39·1 | ·03140 | 9 | 12·87 |
| 4 | 50·6 | ·03105 | 9 | 13·02 |
| 5 | 63·8 | ·03065 | 8 | 13·19 |
| 6 | 80·2 | ·03026 | 8 | 13·36 |
| 7 | 92·9 | ·02944 | 6 | 13·73 |
| 8 | 101·5 | ·02904 | 7 | 13·92 |
| 9 | 110·7 | ·02891 | 8 | 13·98 |
| 10 | 125·3 | ·02950 | 8 | 13·70 |
| 11 | 136·4 | ·03065 | 9 | 13·19 |

| No. | Temp. | Elongation for 500 grams | No. of Observations | M. |
|---|---|---|---|---|
| 12 | 147.1°C | ·03163 Cm. | 8 | 12·78 × 10″ |
| 13 | 154.6 | ·03223 | 8 | 12·54 |
| 14 | 150.7 | ·03268 | 7 | 12·37 |
| 15 | 143.8 | ·03271 | 6 | 12·36 |
| 16 | 136.9 | ·03263 | 8 | 12·39 |
| 17 | 129.5 | ·03231 | 9 | 12·51 |
| 18 | 119.4 | ·03170 | 7 | 12·75 |
| 19 | 108.1 | ·02992 | 8 | 13·51 |
| 20 | 95.0 ~~86.3~~ | ·02887 | 8 | 14·00 |
| 21 | 86.3 | ·02896 | 9 | 13·96 ~~12·33~~ |
| 22 | 70.2 | ·02982 | 9 | 13·56 ~~12·38~~ |
| 23 | 52.8 | ·03067 | 10 | 13·18 ~~12·63~~ |
| 24 | 41.1 | ·03142 | 8 | 12·85 |
| 25 | 29.7 | ·03160 | 8 | 12·79 |
| 26 | 22.3 | ·03193 | 8 | 12·66 |

Total Load = 2 kilos

= 27 kilos per sq. mm.

Table VIII.

| No. | Temp. | Elongation for 500 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 1 | 22·5°C. | ·03195 cm. | 8 | $12{\cdot}65 \times 10^{11}$ |
| 2 | 30·1 | ·031~~8~~75 | 8 | 12·72 |
| 3 | 42·6 | ·03142 | 9 | 12·85 |
| 4 | 55·7 | ·03100 | 9 | 13·04 |
| 5 | 69·9 | ·03044 | 8 | 13·28 |
| 6 | 86·3 | ·03024 | 8 | 13·37 |
| 7 | 100·8 | ·03053 | 9 | 13·24 |
| 8 | 112·2 | ·03076 | 9 | 13·14 |
| 9 | 125·7 | ·03142 | 10 | 12·85 |
| 10 | 136·1 | ·03180 | 10 | 12·71 |

| No. | Temp. | Elongation for 500 grams. | No. of Observations | M. |
|---|---|---|---|---|
| 11 | 144·3°C. | ·03208 cm. | 8 | $12{\cdot}60\times10^{11}$ |
| 12 | 158·2 | ·03236 | 8 | 12·49 |
| 13 | 149·9 | ·03281 | 8 | 12·32 |
| 14 | 141·4 | ·03278 | 9 | 12·33 |
| 15 | 132·5 | ·03265 | 9 | 12·38 |
| 16 | 120·0 | ·03200 | 7 | 12·63 |
| 17 | 109·1 | ·03130 | 7 | 12·92 |
| 18 | 93·6 | ·03033 | 6 | 13·33 |
| 19 | 81·7 | ·03016 | 8 | 13·40 |
| 20 | 65·3 | ·03067 | 8 | 13·18 |
| 21 | 48·9 | ·03116 | 6 | 12·97 |
| 22 | 37·0 | ·03155 | 6 | 12·81 |
| 23 | 28·5 | ·03178 | 8 | 12·72 |
| 24 | 22·6 | ·03195 | 8 | 12·65 |

# Table IX.

| Field. | Load in Kilos per sq mm. | Elongation for ·5 Kilo. | No. of Observations | M. |
|---|---|---|---|---|
| ·41 | 10·6 | ·03143 cm. | 8 | 12·85 x 10" |
| | 13·25 | ·03102 | 10 | 13·02 |
| | 15·9 | ·03046 | 8 | 13·26 |
| | ~~23·8~~ 19·9 | ·03025 | 8 | 13·35 |
| | 23·8 | ·03007 | 9 | 13·43 |
| | 27·0 | ·03039 | 9 | 13·29 |
| | 29·1 | ·03131 | 7 | 12·90 |
| | 27·0 | ·03100 | 6 | 13·03 |
| | 23·8 | ·02989 | 6 | 13·51 |
| | 19·9 | ·02969 | 7 | 13·60 |
| | 15·9 | ·03021 | 9 | 13·37 |
| | 13·25 | ·03048 | 8 | 13·25 |
| | 10·6 | ·03143 | 8 | 12·85 |

# Table X.

| Field. | Load in kilos per sq. mm. | Elongation for ·3 Kilo | No. of Observations | M. |
|---|---|---|---|---|
| 2·5 | 10·6 | ·02974 cm | 7 | 13·58 x 10" |
| | 13·25 | ·02895 | 6 | 13·95 |
| | 15·9 | ·02822 | 9 | 14·31 |
| | 17·9 | ·02762 | 8 | 14·62 |
| | 19·9 | ·02723 | 10 | 14·83 |
| | 23·8 | ·02760 | 8 | 14·63 |
| | 27·0 | ·02905 | 8 | 13·90 |
| | 29·1 | ·03011 | 8 | 13·41 |
| | 27·0 | ·02996 | 8 | 13·48 |
| | 23·8 | ·02911 | 6 | 13·87 |
| | 19·9 | ·02617 | 7 | 15·43 |
| | 17·9 | ·02605 | 9 | 15·50 |
| | 15·9 | ·02669 | 10 | 15·13 |
| | 13·25 | ·02814 | 8 | 14·35 |
| | 10·6 | ·02974 | 8 | 13·58 |

# Table XI.

| Field. | Load in kilos per sq. mms. | Elongation for ·5 Kilo. | No. of Observations | M |
|---|---|---|---|---|
| 4·6 | 10·6 | ·02785 cm. | 9 | 14·30 × 10" |
| | 13·25 | ·02707 | 8 | 14·92 |
| | 15·9 | ·02638 | 6 | 15·31 |
| | 17·9 | ·02611 | 8 | 15·47 |
| | 19·9 | ·02607 | 7 | 15·49 |
| | 23·8 | ·02690 | 9 | 15·01 |
| | 27·0 | ·02848 | 10 | 14·18 |
| | 29·1 | ·02958 | 10 | 13·65 |
| | 27·0 | ·02948 | 8 | 13·70 |
| | 23·8 | ·02809 | 8 | 14·38 |
| | 19·9 | ·02495 | 8 | 16·19 |
| | 17·9 | ·02451 | 8 | 16·48 |
| | 15·9 | ·02495 | 8 | 16·19 |
| | 13·25 | ·02667 | 7 | 15·14 |
| | 10·6 | ·02785 | 8 | 14·50 |

# Table XII.

| Field. | Load in kilos per sq. mm. | Elongation for .5 Kilo. | No. of Observations | M. |
|---|---|---|---|---|
| 7·3 | 10·6 | ·02807 cm. | 8 | 14·38 × 10" |
| | 13·25 | ·02725 | 10 | 14·82 |
| | 15·9 | ·02711 | 8 | 14·90 |
| | 17·9 | ·02723 | 7 | 14·83 |
| | 19·9 | ·02749 | 6 | 14·69 |
| | 23·8 | ·02828 | 6 | 14·28 |
| | 27·0 | ·02918 | 8 | 13·84 |
| | 29·1 | ·02956 | 8 | 13·66 |
| | 27·0 | ·02958 | 9 | 13·65 |
| | 23·8 | ·02885 | 10 | 13·97 |
| | 19·9 | ·02714 | 10 | 14·88 |
| | 17·9 | ·02648 | 9 | 15·25 |
| | 15·9 | ·02650 | 8 | 15·24 |
| | 13·25 | ·02690 | 8 | 15·01 |
| | 10·6 | ·02807 | 7 | 14·38 |

# Table XIII.

| Field | Load in kilos per sq mm. | Elongation for ·3 kilo | No. of Observations | M. |
|---|---|---|---|---|
| 14·2 | 10·6 | ·02954 cm. | 8 | $13·67 \times 10^{11}$ |
| | 13·25 | ·02899 | 7 | 13·93 |
| | 15·9 | ·02907 | 8 | 13·89 |
| | 19·9 | ·02952 | 8 | 13·68 |
| | 23·8 | ·03009 | 6 | 13·42 |
| | 27·0 | ·03067 | 6 | 13·17 |
| | 29·1 | ·03096 | 5 | 13·05 |
| | 27·0 | ·03083 | 6 | 13·10 |
| | 23·8 | ·03027 | 7 | 13·34 |
| | 19·9 | ·02971 | 7 | 13·59 |
| | 15·9 | ·02889 | 8 | 13·98 |
| | 13·25 | ·02885 | 9 | 14·00 |
| | 10·6 | ·02954 | 9 | 13·67 |

# Table XIV.

| Field. | Load in kilos per sq. mm | Elongation for ·5 Kilo | No. of Observations | M. |
|---|---|---|---|---|
| 19·7 | 10·6 | ·03143 cm. | 8 | $12·85 \times 10^{11}$ |
| | 13·25 | ·03151 | 6 | 12·81 |
| | 15·9 | ·03159 | 7 | 12·78 |
| | 19·9 | ·03161 | 8 | 12·77 |
| | 23·8 | ·03185 | 9 | 12·68 |
| | 27·0 | ·03197 | 10 | 12·63 |
| | 29·1 | ·03205 | 9 | 12·60 |
| | 27·0 | ·03195 | 8 | 12·64 |
| | 23·8 | ·03177 | 7 | 12·71 |
| | 19·9 | ·03177 | 6 | 12·71 |
| | 15·9 | ·03166 | 8 | 12·75 |
| | 13·25 | ·03145 | 8 | 12·84 |
| | 10·6 | ·03143 | 8 | 12·85 |

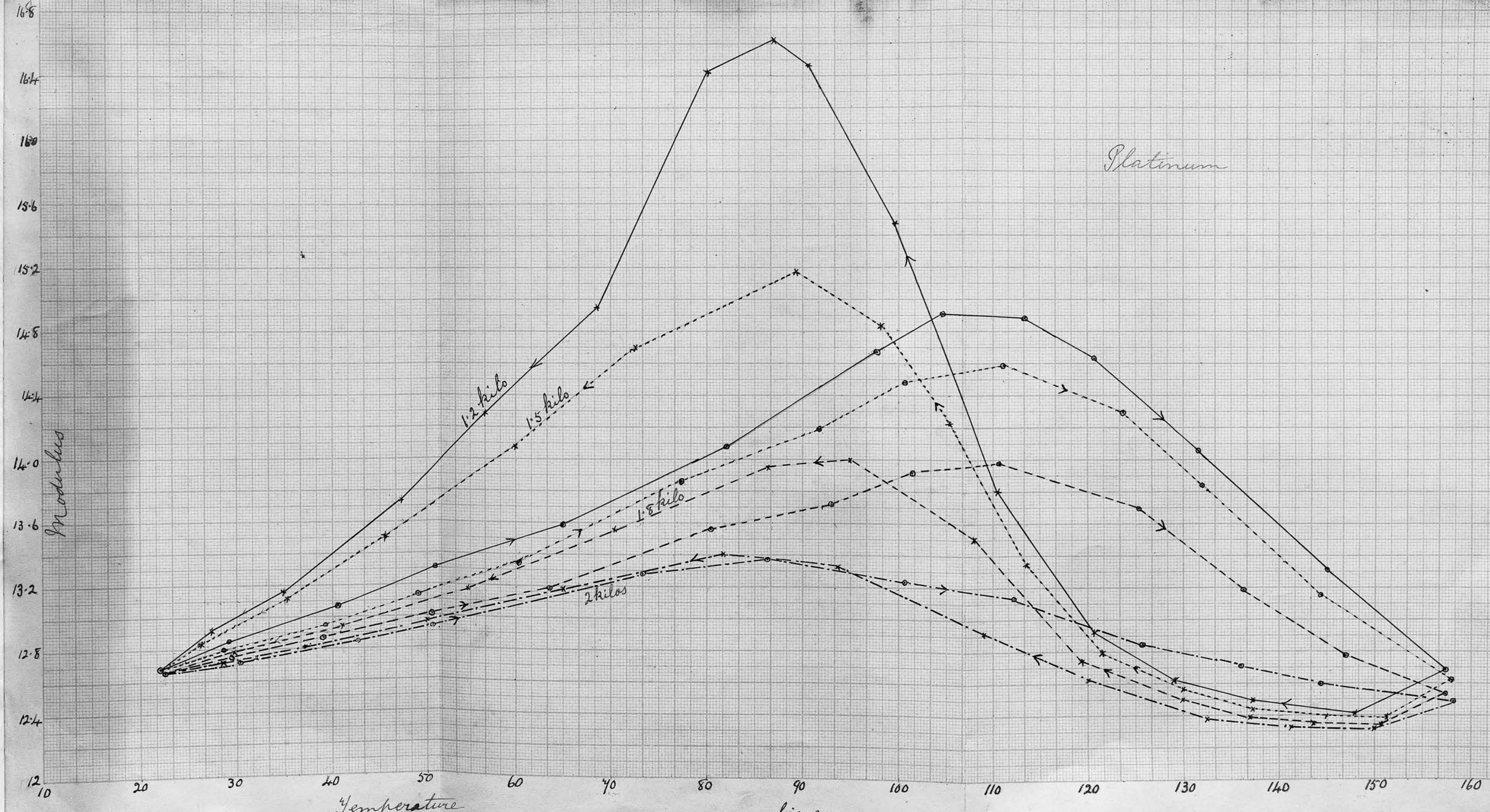

Platinum
1.2 kilo
1.5 kilo
1.8 kilo
2 kilos
Modulus
Temperature
16.8
16.4
16.0
15.6
15.2
14.8
14.4
14.0
13.6
13.2
12.8
12.4
12
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160

fig. 21

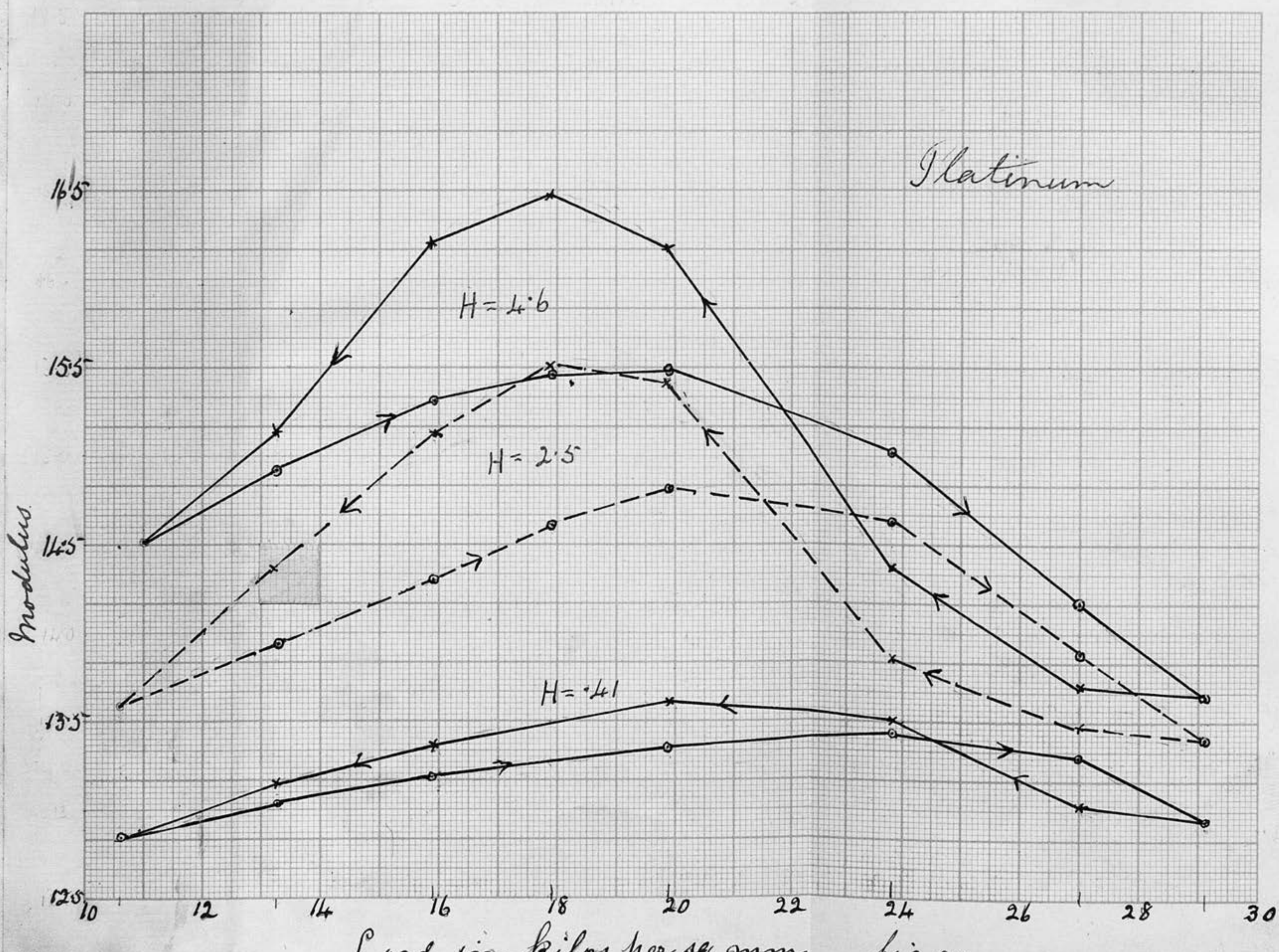
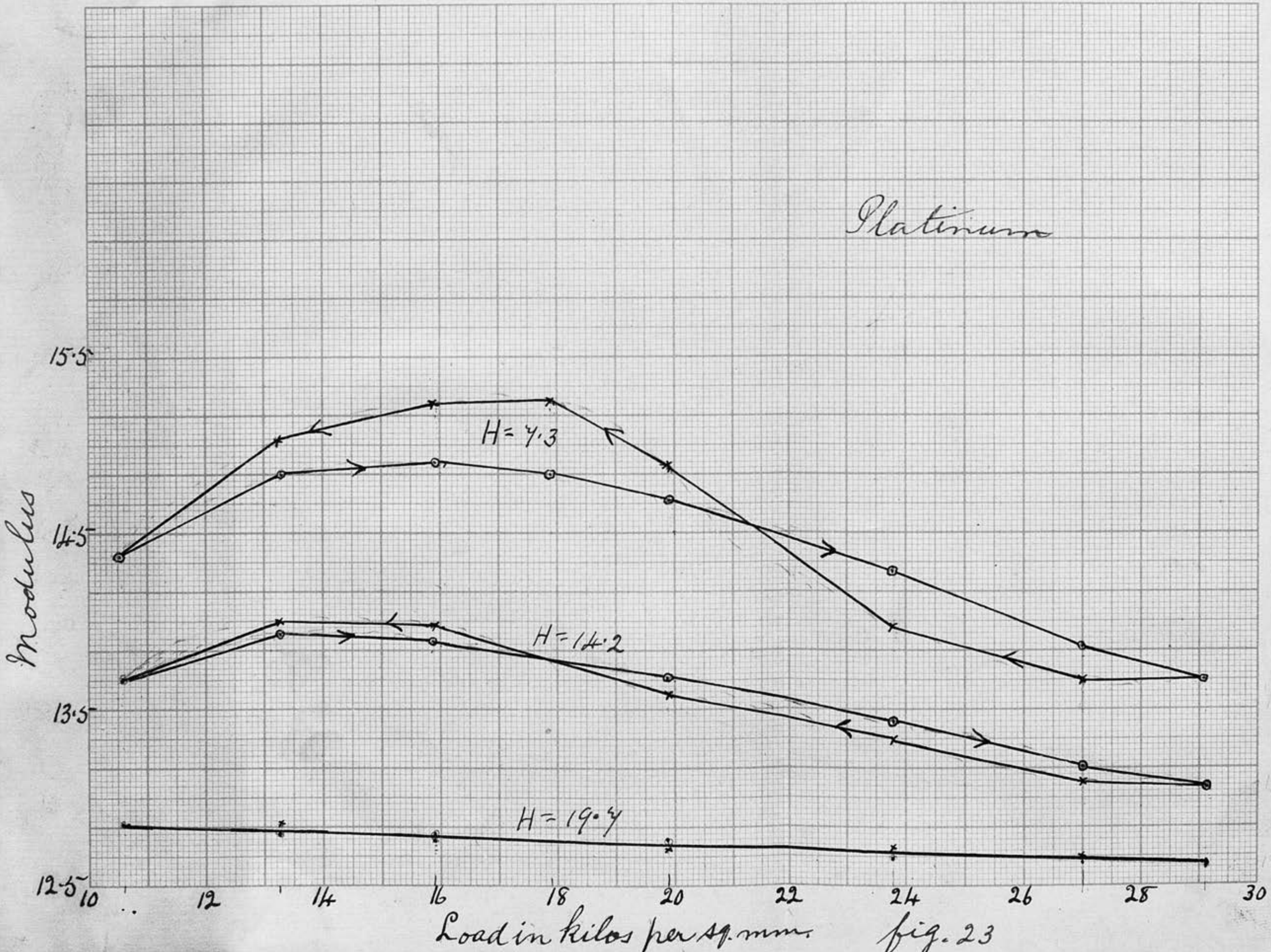

Platinum
H = 4·6
H = 2·5
H = ·41
16·5
15·5
14·5
13·5
12·5
Modulus
10
12
14
16
18
20
22
24
26
28
30
Load in kilos per sq. mm.

fig. 22


Platinum
Modulus
15·5
14·5
13·5
12·5
10
12
14
16
18
20
22
24
26
28
30
H = 7·3
H = 14·2
H = 19·4
Load in kilos per sq. mm.
fig. 23

In concluding this paper let me pass in rapid review the outstanding points established by the different experiments. In all of them there are striking similarities. When the metals are heated by the ordinary method the graphs are uniformly straight lines, and there are no irreversible effects with rise of temperature. If, however, the rise of temperature be caused by current flow the results are more complex, for, when the heating is produced in this way, the variation of the modulus depends on the load. When this is fairly large the results are similar to those obtained with ordinary heating, that is, there are no irreversible effects. But when the load is moderate there are great and most important differences. Both the magnetic and non-magnetic metals exhibit marked hysteresis, which diminishes in amount as the load is increased, and which ultimately vanishes. Again as the load is gradually increased the maximum value is reached in continually diminishing fields; and when the field is kept constant and the load varied the maximum value is reached with contincially diminishing load. Thus we are led to the two important and fundamental facts brought out by the experiments as a whole, — firstly, when rise of temperature is produced by an electric current combined with moderate longitudinal stress, that there are irreversible variations of Young's Modulus in magnetic and non-magnetic metals; and secondly, that the curves exhibiting these variations display a marked similarity in both.

Finally, I desire to place on record my great indebtedness to Professor MacGregor for the loan of books, for access to the libraries of the University and of the Royal Society, for references to the literature of the subject, and also for providing me with two strips of cobalt, as I had found it impossible to obtain rods of a size suitable for these experiments. I desire also to thank Dr Knott, Professor Peddie, and Mr James Russell, Edinburgh, for many helpful suggestions and advice readily and kindly given at all times.